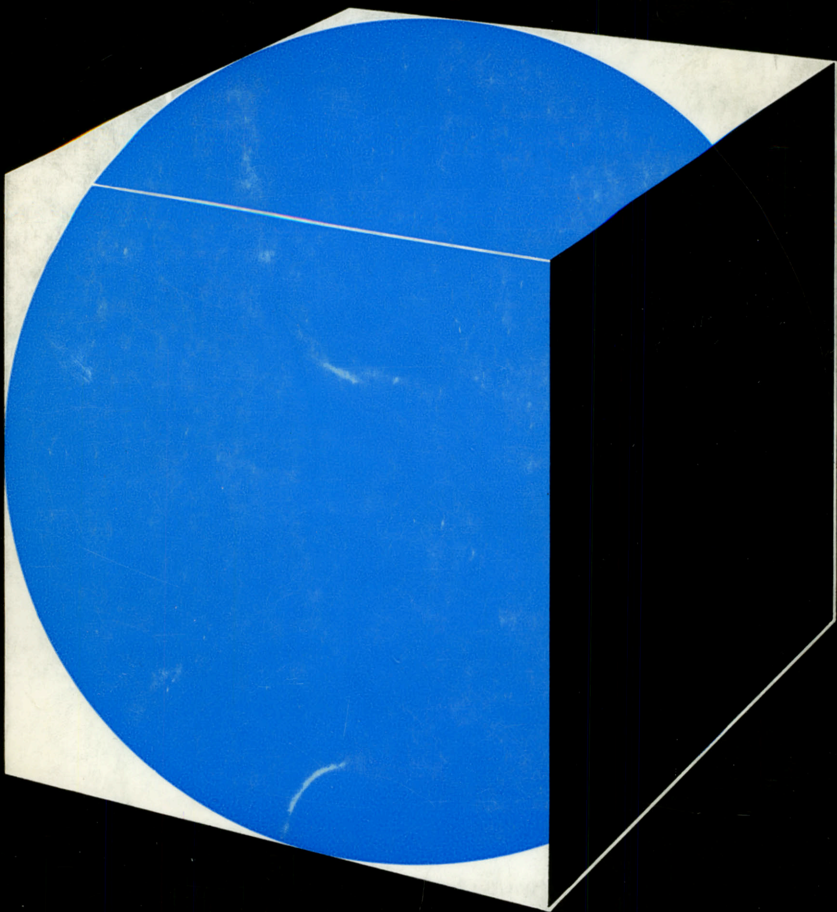
Standards, formulae and charts

Excerpts from international standardization
on acoustical and mechanical measurements.



BRÜEL & KJÆR

Measuring Instruments for Sound and Vibration Measurements

25 years of experience, participation in standardization work, and intensive research and development work in our laboratories enable us to produce a wide range of modern equipment for measurements within the fields of acoustics and vibration.

We hope this booklet will help you find the information on standardization you might need.

For further information on measurement techniques please ask for our booklets: "Acoustic Noise Measurements"
"Architectural Acoustics" and
"Power Spectral Density and Frequency Analysis"
or ask us to put your name on our mailing list for "Technical Review". The Review is issued four times a year in English, German, and French and describes the latest measurement techniques and measuring results within acoustics and vibration.

For detailed information on our measuring instruments we shall be glad to send you our shortform catalogue issued in more than 14 languages or our main catalogue issued in English and German. All literature is mailed free of charge.

International Standardization

The object of international standardization is to set up a "set of rules" which facilitates the international exchange of goods and services and develop mutual cooperation in the sphere of intellectual, scientific, technological and economic activity. For the time being two international bodies exist for international standardization, the International Electrotechnical Commission (IEC) and the International Organization for Standardization (ISO).

The IEC originates from 1904 and deals with all informational standardization questions of an electrotechnical character, while the ISO was created in 1947 and covers widely different fields, – but not that of electricity. IEC was affiliated to the ISO in 1947 and functions as the Electrical Division of the ISO.

Both the ISO and IEC issue Recommendations.

These Recommendations are Draft Recommendations which are accepted by a majority of the national committees.

However, before a Draft Recommendation is issued a number of meetings and discussions have taken place among the members of the technical committees dealing with the specific subjects.

In the following a number of the international Recommendations and Draft Recommendations which are related to the use of the instruments produced by Brüel & Kjær will be briefly summarized. Recommendations regarding specifications and measuring technique in general are only mentioned while Recommendations of a more specific nature are described more thoroughly.

The approved standards can be obtained from National Standard Organization Offices or from the Secretariat, International Organization for Standardization, 1, Rue de Varembé, Geneva, Switzerland.

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Practical Formulae and Curves

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IEC Recommendation Publication 50

International Electrotechnical Vocabulary

A glossary of the terms, with their definitions, in English and French used in electrical engineering. The equivalent terms only are given in Dutch, German, Italian, Polish, Swedish and Spanish.

Publication 50(07) deals with Electronics. Publication 50(08) deals with Electro-acoustics.

IEC Recommendation Publication 68-2-6

Basic Environmental Testing Procedures for Electronic Components and Electronic Equipment

Test F: Vibration

After having stated the purpose and scope of the Recommendation three general test stages are defined. These are: 1) Initial resonance search, 2) Endurance and 3) Final resonance search. If there are any differences in resonant behaviour from 1) to 2) the reason for these differences should be investigated. The endurence may be performed at a number of selected frequencies (or narrow bands of frequencies) or by sweeping, dependent upon the kind of specimen(s) being tested and the expected service conditions.

Also certain recommendations are suggested for the mounting of the test specimen(s) and requirements to the vibration system laid down.

It is for instance required that the vibration generator, when loaded, should move in such a manner that the total RMS harmonic content of the vibration signal at the specimen fixing points should be less than 25 % up to 5,000 Hz unless compensated for by increasing the driving amplitude so as to restore the amplitude at the fundamental frequency to the specified value. Furthermore the vibration level at the fixing points in any other than the desired test direction should not exceed 25 % of the specified vibration test. The vibration level in the required direction should be kept within certain tolerances (ranging from ± 10 % to ± 25 %) and the frequency determination should be made with an accuracy of ± 0.5 % or 0.5 Hz whichever is the greater.

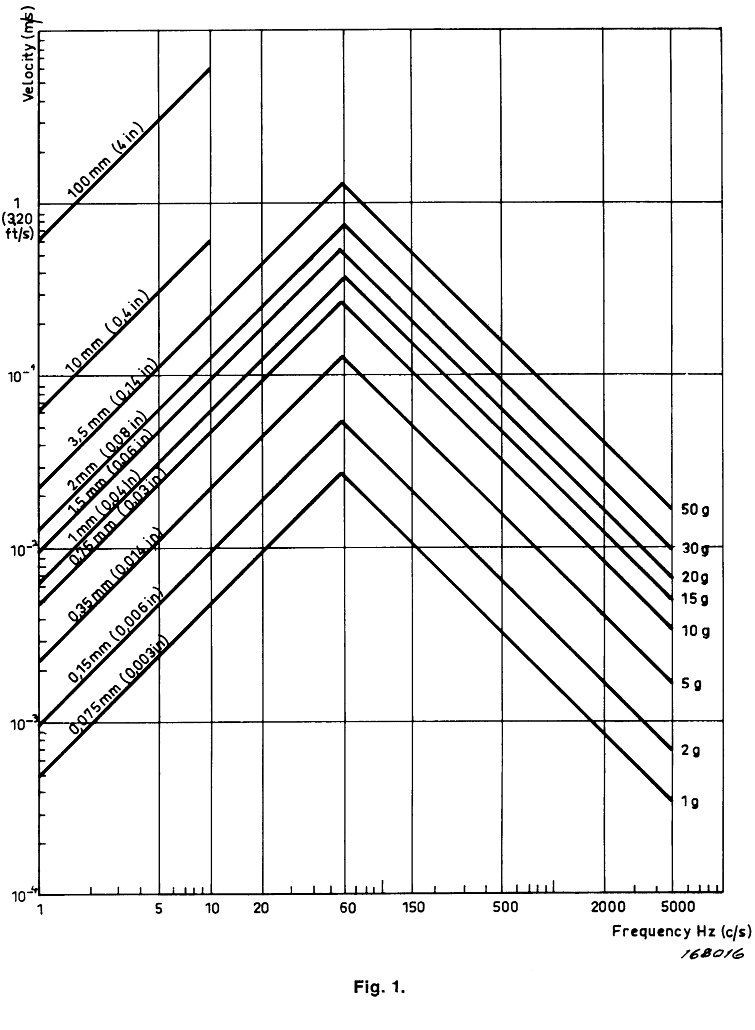

Fig. 1.

A Supplement to Publication 68-2-6 (1966), marked Publication 68-2-6A has been issued in 1967 stating the preferred severities primarily intended for the testing of components. These are:

Sweep endurance:

Total duration

Amplitude*) / Frequency range	0.35 mm or 5 g	0.75 mm or 10 g	1.5 mm or 20 g
10–55 Hz	1.5 h[3])	6 h[2])	–
10–500 Hz	6 h	6 h[1])	–
10–2,000 Hz	–	6 h	6 h

Endurance conditioning at resonance frequencies:

The preferred durations for the conditioning at each resonant frequency in each direction are:

10 min
30 min
10 h.

A further Supplement marked Publication 68 - 2 - 6B, also issued in 1967 describes the considerations on which the vibration test is based.

IEC Recommendation Publication 68 - 2 - 27

Basic Environmental Testing Procedures for Electronic Components and Electronic Equipment. Test Ea: Shock

The Recommendation discusses the purpose of shock testing and specifies the use of three acceleration versus time pulse shapes: The half-sine pulse, the final-peak saw-tooth and the trapezoidal pulse. The specifications are at present given in terms of prescribed pulses with tolerances rather than shock spectra. It then goes on specifying the conditions for testing and the measuring system. The frequency response of the measuring system is laid down as shown in Fig. 2.

Also, recommendations are given for the mounting of the specimen, whether it be an equipment or a component, and a table (Table I, below) regarding recommended test severities is included.

Finally, the testing procedure and the information required in the relevant test specification are specified.

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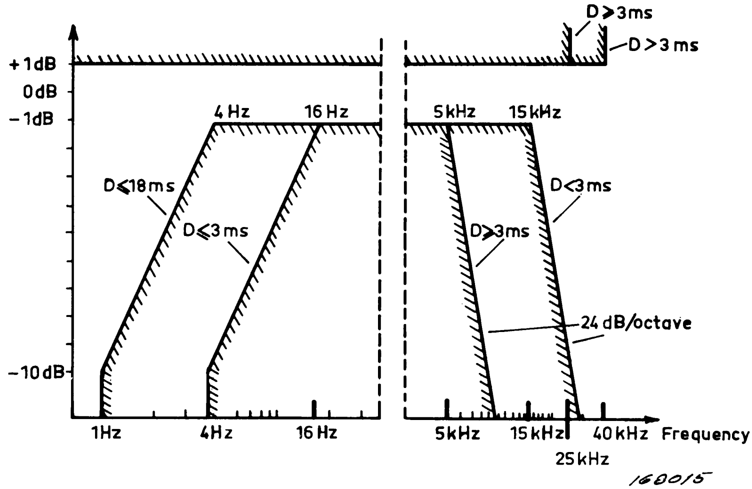
*) Displacement amplitude below the cross-over frequency or acceleration amplitude above the cross-over frequency.

Notes 1. — Other preferred severities are under consideration.
2. — Some of these severities correspond to severities given in IEC Recommendation 68-2, Test F (1960) except in duration.



Duration of pulse (ms)	Low-frequency cut-off (Hz)		High-frequency cut-off (kHz)	Frequency beyond which the response may rise above + 1 dB (kHz)
	− 1 dB	− 10 dB	− 1 dB	
< 3	16	4	15	40
3	16	4	5	25
$3 < D \leqq 18$	4	1	5	25

Fig. 2. Frequency characteristics of the measuring system.

TABLE I

Peak acceleration (A)		Corresponding duration of the pulse (D)	Corresponding velocity change		
			Final-peak Saw-tooth	Half-sine	Trapezoidal
m/s²	(Equivalent g)	ms	m/s (ft/s)	m/s (ft/s)	m/s (ft/s)
147	(15)	11	0.81 (2.65)	1.03 (3.38)	1.46 (4.78)
294	**(30)**	**18**	**2.65 (8.68)**	**3.37 (11.1)**	**4.77 (15.7)**
294	(30)	11	1.62 (5.30)	2.06 (6.76)	2.91 (9.56)
294	(30)	6	0.88 (2.89)	1.12 (3.69)	1.59 (5.22)
490	**(50)**	**11**	**2.69 (8.84)**	**3.43 (11.3)**	**4.86 (15.9)**
490	(50)	3	0.74 (2.41)	0.93 (3.07)	1.32 (4.35)
981	(100)	11	5.39 (17.7)	6.86 (22.5)	9.71 (31.9)
981	**(100)**	**6**	**2.94 (9.65)**	**3.74 (12.3)**	**5.30 (17.4)**
1 960	(200)	6	5.88 (19.3)	7.49 (24.6)	10.60 (34.8)
1 960	(200)	3	2.94 (9.65)	3.74 (12.3)	5.30 (17.4)
4 900	**(500)**	**1**	**2.45 (8.04)**	**3.12 (10.2)**	**4.42 (14.5)**
9 810	(1 000)	1	4.90 (16.1)	6.24 (20.5)	8.83 (29.0)
14 700	**(1 500)**	**0.5**	**3.68 (12.1)**	**4.68 (15.4)**	**6.62 (21.7)**
29 400	(3 000)	0.2	2.94 (9.65)	3.74 (12.3)	5.30 (17.4)

IEC Recommendation Publication 89

Recommendations for the characteristics of audio apparatus to be specified for application purposes

Lists and defines the characteristics of audio frequency apparatus useful for their specification. Does not lay down performance criteria.

IEC Recommendation Publication 98

Recommendations for lateral-cut commercial and transcription disc recordings. Amendment sheet No. 1, June 1959. Gives the most important dimensional features and recording and reproducing characteristics necessary to secure interchangeability of recordings. Those clauses dealing with professional applications are in conformity with the corresponding CCIR recommendations.

Also some details on the reproducing equipment (pick-up) such as reproducing stylus tip radius, included angle of tip and colour coding are given.

Publication 98-1 (1959) Supplement to Publication 98: Recommendations for Stereophonic commercial disc records. Extends Publication 98, with which it must be used, to cover stereophonic disc records and reproducing equipment (pick-up).

IEC Recommendation Publication 118

Recommended methods for measurement of the electro-acoustical characteristics of hearing aids

The recommendation contains four sections:

1) *Object.* This section also states that the test procedure is based on the free-field technique, in which the hearing aid is placed in a plane progressive wave, with the earphone coupled to a standardized coupler.

2) *Explanation of terms.*

3) *Test Equipment.* Here is stated that the test enclosure shall provide essentially free-field conditions over the frequency range 200–5,000 Hz and that the noise in the enclosure shall be at least 20 dB, and under no condition less than 10 dB, below the lowest input sound pressure level.

The sound source shall keep the sound pressure level within ± 2 % of the desired value.

For response measurement the total harmonic distortion of the source shall not exceed 2 %, for distortion measurement not 0.5 % It is recommended to use the IEC 2 cm^3 reference coupler as artificial ear, and the overall accuracy of the complete test arrangement shall, if possible, be within ± 1.5 dB. The output indicator used shall give RMS indication to the closest possible approximation.

4) *Test Procedure.* The procedure for calibrating the sound field, locating the hearing aid, and for making measurements are described. A set of rules for measurements on the hearing aid under normal operating conditions is given. The effects of gain control and tone control positions upon the frequency response are to be determined separately.

Also the basic and comprehensive frequency response shall be measured. (Input sound pressure levels: 50, 60 (basic), 70 and 80 dB). The gain control of the hearing aid shall during these measurements be adjusted to give a sound pressure level in the coupler of 100 dB ± 2 dB at 1,000 Hz with an input sound pressure level of 60 dB. It is recommended also to measure the saturation sound pressure level in the coupler with the gain control of the hearing aid turned full on, as well as the maximum acoustic gain.

To determine the effects on acoustic gain of variation of battery or supply voltage and internal resistance special measuring arrangements are suggested. It is also suggested to measure the frequency response and electrical impedance of the earphone.

The measurement of harmonic distortion shall be carried out with an input free-field sound pressure level of 60 dB at the frequencies 400, 1,000 and 1,500 Hz, and a special procedure is recommended to determine the effect on harmonic distortion of variation of battery or supply voltage. It is suggested to measure the random noise from the hearing aid and finally the battery current shall be measured.

IEC Recommendation Publication 123

Recommendations for sound level meters

These Recommendations apply to sound level meters for general purposes only. They do not apply to precision sound level meters nor to apparatus for measuring sounds of very short duration or discontinuous sounds.

The recommendations contain a number of sections and define some general as well as specific technical characteristics of the sound level meter:

It shall cover the frequency range 31.5 to 8,000 Hz and shall include at least one of the three different response curves called A, B and C, – see Table 1. The tolerances permitted are relatively large, they relate to the whole apparatus, however, and apply to the functioning of the apparatus in a free sound field in a particular direction which shall be specified by the manufacturer. Correction for measurements in a diffuse sound field shall also be indicated and the apparatus shall fulfil certain requirements with regard to its dynamic range.

The microphone shall be of the omnidirectional type Permissible tolerances on microphone sensitivity on an angle of $\pm$ 90° are given in Table II and relate to the measuring apparatus only, any observer being effectively outside the sound field.

The indicating instrument shall be of the square-law type and the scale graduated in steps of 1 dB over an interval of 15 dB. It shall possess a specific dynamic characteristic designated as Fast and may also be provided with a second specific dynamic characteristic designated as Slow.

The amplifier shall posses certain characteristics with respect to the effects of thermal noise and microphonics, shall have a power handling capacity at least 10 dB greater than that corresponding to full scale deflection on the meter and means shall be provided for electrical calibration. If battery operated provision shall also be present for checking the battery voltage under load. The temperature and humidity ranges of the amplifier shall be stated by the manufacturer and the effects of vibration and magnetic and electrostatic fields reduced as far as possible. Connections of external apparatus having a specified impedance shall not affect the meter indication by more than 1 dB.

For the determination of the sensitivity of the complete apparatus in a diffuse sound field a specific procedure is outlined, and the verification of the quadratic law of addition of the indicator should be carried out according to the two-tone test. Certain procedures are also stated for checking the dynamic characteristics of the meter, its calibration and the accuracy of the attenuator.

Finally certain requirements are laid down with regard to the marking of the instrument and the information supplied from the manufacturer in the form of a description leaflet.

IEC Recommendation Publication 126

IEC reference coupler for the measurement of hearing aids using earphones coupled to the ear by means of ear inserts

The recommendation contains three sections:

1) *Scope and Purpose.*

2) *Definition.*

3) *Construction.* In this section a number of construction details are given and examples of constructions shown, see Fig. 1. It is stated that the coupler volume shall be 2 cm^3 $\pm$ 1 % and that the coupler shall have a mass of at least 100 g, including microphone. The diameter of the cylindrical cavity shall be not less than 18.0 mm

(0.709 in) and not greater than 21.0 mm (0.827 in). Static pressure equalization shall be accomplished by means of a partially filled capillary tube. Certain requirements are also laid down for the measuring microphone which shall be a calibrated pressure microphone located along the axis of the coupler. The connection of the hearing aid to the coupler should, when possible, be made by replacing the ear insert by an ear mould substitute (Fig. 1).

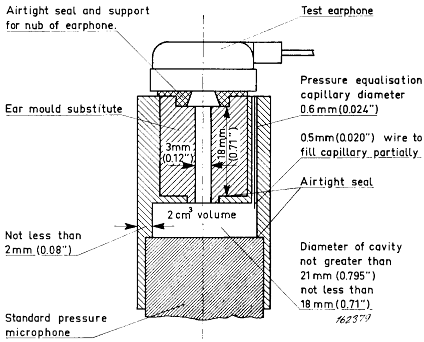


Fig. 1.

IEC Recommendation Publication 177

Specification for pure tone audiometers for general diagnostic purposes

After the introduction of the scope of the recommendation and the explanation of terms follows a section on requirements for monaural air-conduction hearing tests. Test tones shall be provided of frequencies 250, 500, 1,000, 2,000, 3,000, 4,000, 6,000, 8,000 Hz (at least) and frequencies of 125, 750 and 1,500 Hz are optional. The frequency accuracy shall be within ± 3 % and the sound pressure level of each harmonic component of each tone at each setting of the attenuator shall be at least 30 dB below that of the fundamental component when measured with the earphone applied to an artificial ear ($d_{tot} < 5$ %).

It shall be possible to adjust the sound pressure level of each tone in 5 dB steps, and certain requirements are laid down for the transient behaviour of the keying device (tone switch).

The construction of the earphone shall permit close sealing, and the earphone shall be calibrated on an artificial ear in comparison with a reference earphone. The range and accuracy of sound pressure levels produced by the earphone are also stated.

Also some requirements for bone conduction hearing tests are laid down and further extended in an appendix to the recommendations. At least five test tones shall be provided of frequencies 250, 500, 1,000, 2,000, 3,000 and 4,000 Hz accuracy ± 3 %, and the bone conduction receiver should be made of hard material and have an overall diameter of 1.5 ± 0.1 cm. The recommended force of application is 7.5 ± 0.5 N. It is required that the audiometer is provided with a masking device and certain specifications for this device are suggested.

Some general characteristics such as noise from the audiometer, unwanted sound, temperature and supply voltage stability and safety requirements are also discussed.

IEC Recommendation Publication 178

Specification for pure-tone, screening audiometers

These recommendations apply to audiometers for screening purpose using air-conduction hearing tests only.

The requirements to this instrument are similar to those described in the above draft for audiometers for general diagnostic purposes except that the test tone of 8,000 Hz is omitted, a narrower dynamic range is allowed and the requirements for bone-conduction tests and provision of a masking device omitted.

An appendix gives suggestions regarding tests for unwanted sound from the audiometer.

IEC Recommendation Publication 179

Specification for precision sound level meters

The recommendations specify the characteristics of an apparatus to measure accurately certain weighted sound pressure levels, but does not apply to apparatus for measuring sounds of very short duration or discontinuous sounds. It is specially pointed out that the manner of use will determine in large part the validity of any measurement made with an instrument that meets this specification and in particular care must be exercised so that the presence of the observer does not invalidate the calibration.

A precision sound level meter shall include at least one of the three weighting networks called A, B, C and shall cover the frequency range defined in Table I within the stated tolerances. The tolerances relate to the whole apparatus and apply to the functioning of the apparatus in a freed sound field in a direction specified by the manufacturer. At 1,000 Hz the reading of the precision sound level meter shall be the sound pressure level excisting before the introduction of the apparatus within a tolerance of ± 1 dB under specified reference conditions.

The microphone shall be of the omnidirectional pressure type. Permissible tolerances on the variation of sensitivity with angle are given in Table II and relate to the normal mounting of the apparatus, the observer being in a position specified by the manufacturer.

The requirements to the characteristics of the indicating instrument are similar to those for sound level meters (IEC Publication 123) except for stricter tolerances.

Table I

Frequency Hz	Curve A dB	Curve B dB	Curve C dB	Tolerances (dB) allowed for **precision** sound level meters		Tolerances (dB) allowed for sound level meters	
10	−70.4	−38.2	−14.3	5	−∞	5	−∞
12.5	−63.4	−33.2	−11.2	5	−∞	5	−∞
16	−56.7	−28.5	−8.5	5	−∞	5	−∞
20	−50.5	−24.2	−6.2	5	−5	5	−∞
25	−44.7	−20.4	−4.4	5	−5	5	−∞
31.5	−39.4	−17.1	−3.0	3	−3	5	−5
40	−34.6	−14.2	−2.0	3	−3	4.5	−4.5
50	−30.2	−11.6	−1.3	3	−3	4	−4
63	−26.2	−9.3	−0.8	3	−3	4	−4
80	−22.5	−7.4	−0.5	2	−2	3.5	−3.5
100	−19.1	−5.6	−0.3	1	−1	3.5	−3.5
125	−16.1	−4.2	−0.2	1	−1	3	−3
160	−13.4	−3.0	−0.1	1	−1	3	−3
200	−10.9	−2.0	0	1	−1	3	−3
250	−8.6	−1.3	0	1	−1	3	−3
315	−6.6	−0.8	0	1	−1	3	−3
400	−4.8	−0.5	0	1	−1	3	−3
500	−3.2	−0.3	0	1	−1	3	−3
630	−1.9	−0.1	0	1	−1	3	−3
800	−0.8	0	0	1	−1	2.5	−2.5
1000	0	0	0	1	−1	2	−2
1250	0.6	0	0	1	−1	2.5	−2.5
1600	1.0	0	−0.1	1	−1	3	−3
2000	1.2	−0.1	−0.2	1	−1	3	−3
2500	1.3	−0.2	−0.3	1	−1	4	−3
3150	1.2	−0.4	−0.5	1	−1	5	−3.5
4000	1.0	−0.7	−0.8	1	−1	5.5	−4
5000	0.5	−1.2	−1.3	1.5	−1.5	6	−4.5
6300	−0.1	−1.9	−2.0	1.5	−2	6	−5
8000	−1.1	−2.9	−3.0	1.5	−3	6	−6
10000	−2.5	−4.3	−4.4	2	−4	6	−∞
12500	−4.3	−6.1	−6.2	3	−6	6	−∞
16000	−6.6	−8.4	−8.5	3	−∞	6	−∞
20000	−9.3	−11.1	−11.2	3	−∞	6	−∞

Also the requirements to the amplifier are of a type similar to those stated in IEC Publication 123. However, certain specified measurement conditions are laid down for determining the various characteristics. The amplifier shall be capable of operating (with correction data supplied from the manufacturer) over a temperature range −10° to 50°C, and any effect of humidity shall be less than 0.5 dB between 0 and 90 % relative humidity. The overload factor shall be greater than 12 dB, and the connection of external apparatus having a specified impedance shall not affect the meter indication by more than 0.5 dB.

For determination of the sensitivity of the complete apparatus in a diffuse sound field and the verification of the quadratic law of addition of the indicator the procedures outlined in IEC Publication 123 are used.

The tolerances allowed for the indicator are, however, much stricter than required in Publication 123.

In addition to the procedures given for checking the dynamic characteristics of the meter, its calibration and the accuracy of the attenuator a special procedure is outlined to test precision sound level meters designed for the measurement of sound pressure levels greater than 100 dB with regard to microphonics.

Finally requirements as to the marking of the instrument and information contained in the instruction book are laid down.

Table II

Permissible tolerances on microphone sensitivity over an angle of ± 90°

Frequency Hz	Tolerances for sound level meters		Tolerances for precision sound level meters	
	Column A	Column B	Angles up to ± 90°	Angles less than 30°
31.5–500	± 1	± 1	± 1	± 0.5
up to 1000	± 1.5	+ 1–2	± 1	± 0.5
» 2000	± 4	+ 1–6	+ 1–2	± 0.5
» 4000	± 8	+ 1–8	+1–3	+ 0.5–1
» 8000	± 15	+ 1–15	+ 1–6	+ 0.5–1.5
» 8000–12500	not specified	not specified	+ 1–10	+ 0.5–2

Remarks: The values given in Column A refer to measurements made with the microphone mounted on the sound level meter as for use, any observer being effectively outside the sound field.

The values given in Column B refer to measurements made on the microphone alone, physically separated from the sound level meter proper, but electrically connected thereto, any observer being effectively outside the sound field.

IEC Recommendation Publication 200

Recommended Methods of Measurement for Loudspeakers

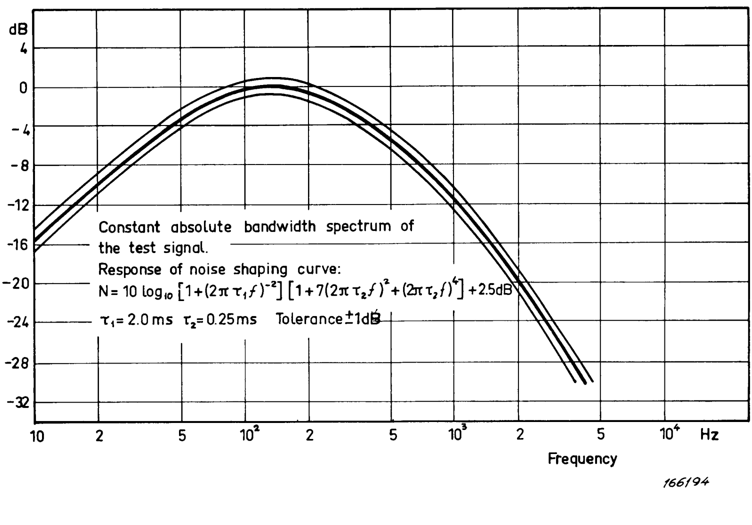
The Draft contains four sections: 1. Forward/Scope. 2. Explanation of terms used in conjunction with loud-speaker measurements. 3. General test conditions, and 4. Measurements.

In section 3 it is stated that acoustical measurements should be made under free-field conditions, and the background noise should not influence the results by more than ± 1 dB. The accuracy should be stated in the form of ± 2 and ± 5 dB frequency limits.

The acoustic loading and mounting of the loudspeaker during measurement should be stated, and where the loudspeaker is not designed to be used with a specific enclosure the use of a standard baffle is suggested.

Measurement of the response curves are to be made with a pressure microphone, having a known free-field calibration, mounted at a distance of 50 cm from the reference point. (For loudspeakers greater than 25 cm in diameter a measuring distance of 1 meter is to be preferred). It is recommended that response curves be taken by an automatic method giving a continuous curve.

In section 4 the various types of recommended characteristic measurements are described, such as measurement of the frequency response, direction response pattern, directivity factor and index, electrical impedance and resonance frequency, characteristic sensitivity, rated sound pressure level and power handling capacity. It is recommended that measurements be made, either at a constant voltage, or at a constant current and at a nominal power of 1/10th of the rated power handling capacity.



The direction response pattern should preferably be measured by means of a device giving a continuous angular deviation, and curves be drawn for at least the following frequencies: 500, 1,000, 2,000, 4,000 and 8,000 Hz.

Measurement of electrical impedance and resonance frequency should be made without baffle and at, either constant voltage, or constant current. The characteristic sensitivity and rated sound pressure level are calculated from the results of the response measurements and referred to a distance of 1 metre from the reference point.

Finally, the power handling capacity of a loudspeaker should be measured by means of a noise signal in a room not less than 8 m^3, the speaker being mounted without a baffle. The spectrum of the test signal should be specially "shaped" (see figure) and the dynamic conditions for the test specified.

IEC Recommendation Publication 225

Octave, Half-octave and Third-octave
Band Filters Intended for the Analysis of Sounds and Vibrations

After defining the scope and object of the Recommendation the actually recommended midband frequencies are laid down. (These correspond to the preferred frequencies specified in ISO Recommendation R. 266). In section four the terminating impedances of the filters are discussed and it is recommended that it be always possible to use a 600 Ω termination and that a high impedance termination preferably above 10,000 Ω should also be available Section five states that for a 600 Ω filter, the peak value of the permissible e.m.f. applied via a 600 Ω resistor to the input should be at least 2.2 V (i.e. $2 \times 0.775 \sqrt{2}$).

The actual requirements to the filter attenuation characteristics are laid down in section six and tabulated below. Furthermore, it is stated that the effective filter bandwidth should be given by the manufacturer and preferably be within ± 10 % of the nominal filter pass-band.

Finally in sections seven through twelve certain general recommendations, are given with regard to non-linearity, distortion (harmonic distortion), effects of battery voltage, influence of magnetic and electrostatic fields, influence of vibration and ambient sound fields, influence of temperature and influence of humidity.

Variation Δ of the attenuation, with respect to the nominal insertion loss

Frequency range			Attenuation dB
Octave filters	Half-octave filters	Third-octave filters	
From $\frac{f_m}{\sqrt[4]{2}} = 0.8409\ f_m$ To $f_m \sqrt[4]{2} = 1.1892\ f_m$	From $\frac{f_m}{\sqrt[8]{2}} = 0.9170\ f_m$ To $f_m \sqrt[8]{2} = 1.0905\ f_m$	From $\frac{f_m}{\sqrt[12]{2}} = 0.9439\ f_m$ To $f_m \sqrt[12]{2} = 1.0595\ f_m$	$-0.5 \leq \Delta \leq 1$
* From $\frac{f_m}{\sqrt{2}} = 0.7071\ f_m$ To $f_m \sqrt{2} = 1.4142\ f_m$	* From $\frac{f_m}{\sqrt[4]{2}} = 0.8409\ f_m$ To $f_m \sqrt[4]{2} = 1.1892\ f_m$	* From $\frac{f_m}{\sqrt[6]{2}} = 0.8909\ f_m$ To $f_m \sqrt[6]{2} = 1.1225\ f_m$	$-0.5 \leq \Delta \leq 6$
At $\frac{f_m}{2}$ and $2\ f_m$	At $\frac{f_m}{\sqrt{2}} = 0.7071\ f_m$ And $f_m \sqrt{2} = 1.4142\ f_m$	–	≥ 18
–	–	At $\frac{f_m}{\sqrt[3]{2}} = 0.7937\ f_m$ And $f_m \sqrt[3]{2} = 1.2599\ f_m$	≥ 13
Below $\frac{f_m}{4}$ And above $4\ f_m$	–	–	≥ 40
–	Below $\frac{f_m}{4}$ And above $4\ f_m$	Below $\frac{f_m}{4}$ And above $4\ f_m$	≥ 50
Below $\frac{f_m}{8}$ And above $8\ f_m$	Below $\frac{f_m}{8}$ And above $8\ f_m$	Below $\frac{f_m}{8}$ And above $8\ f_m$	≥ 60

* These are the band defining frequencies

IEC Draft Recommendation

Scales and Sizes for Plotting Frequency Characteristics

The Draft contains two sections, the first of these deschribing the need for and use of standardized scale ratios in graphs where a response is plotted as a level (in decibels) against frequency on a logarithmic scale.

In the second section recommendations with regard to actual scale ratios are laid down, the recommended ratios being those for which the length for a 10 : 1 frequency ratio is equal to the length for 10, 25 or 50 dB on the ordinate scale.

ISO

ISO Recommendation R. 131

Expression of the physical and subjective magnitudes of sound or noise

In section 1 of this recommendation it is stated that the physical magnitude of sound or noise should be given as the sound pressure level and expressed as $20 \log_{10} \frac{p}{p_0}$ dB, where p is the measured sound pressure and p_0 is a reference sound pressure of 2×10^{-4} dyn/cm² (μbar) $= 2 \times 10^{-5}$ N/m².

Section 2 defines the subjective loudness level which is expressed in phons. Under certain, specified measurement conditions the phon is identical to the sound pressure level at 1,000 Hz.

Finally section 3 defines a loudness scale. The loudness is measured in sones and provides a numerical designation of loudness that is proportional to the subjective magnitude as estimated by normal observers. The relation between sones, S, and phons, P, is given as:

$$S = 2^{\frac{p - 40}{10}}$$

and a table covering this relation for values between 20 and 120 phons is included.

ISO Recommendation R. 140

Field and laboratory measurements of airborne and impact sound transmission

After defining the scope of the recommendation some general definitions are given:

1) **Average sound pressure level (L)** in a room is defined as:

$$L = 10 \log_{10} \frac{p_1^2 + p_2^2 + \ldots p_n^2}{n \times p_0^2} \text{ dB}$$

where $p_1, p_2 \ldots . p_n$ = RMS sound pressures at n different positions in the room

p_0 = reference sound pressure level (e.g. 2×10^{-4} dyn/cm²)

2) **Average sound pressure level difference (level difference) (D):** $D = L_1 - L_2$.

where L_1 = average sound pressure level in the source room

L_2 = average sound pressure level in the receiving room

3) **Normalized level difference** (D_n):

$$D_n = D + 10 \log_{10} (A/A_0)$$

where D = measured level difference

A = measured absorption in the receiving room

A_0 = reference absorption (commonly taken as 10 m²)

4) **Sound reduction index (R) or Transmission loss:**

$$R = L_1 - L_2 + 10 \log (S/A)$$

where L_1 = average sound pressure level in source room
L_2 = average sound pressure level in receiving room
S = area of test specimen
A = total absorption in the receiving room

5) **Normalized impact sound level (L_n)** in the receiving room in a specific frequency band:

$$L_n = L - 10 \log_{10} (A_0/A)$$

where L = average sound pressure level produced by a standard tapping machine in the receiving room
A = measured absorption in the receiving room
A_0 = reference absorption (commonly taken as 10 m^2)

In section 3 some recommendations with regard to field measurements of airborne sound transmission are given. It is stated that warble tones or white noise from continuously sounding sources should be used. If a warble tone is used the frequency deviation should be at least ± 10 per cent of the mean frequency, at a modulation frequency of about 6 Hz, except that for frequencies above 500 Hz a frequency deviation of ± 50 Hz is sufficient. If white noise is used measurements should be made with one third or half octave band pass filters. Certain requirements are laid down for the filter characteristics and measurements should be taken in the frequency range 100 Hz (125 Hz) to 3,200 Hz (4,000 Hz).

The result of the measurements should be given, at each measurement frequency in the form of the normalized level difference (preferably in the form of a curve).

Section 4 contains recommendations for laboratory measurements of the airborne sound reduction index (R) or transmission loss.

Requirements are laid down for the size of reverberation test rooms (> 50 m^3, preferably > 100 m^3) and also to the size of the test panel (approximately 10 m^2).

Section 5 deals with field measurements and section 6 with laboratory measurements of impact sound transmission. It is stated that the sound field should be generated by a standardized tapping machine containing 5 hammers placed in line, each having a mass of 0.5 kg (± 2.5 %). The hammers should drop the equivalent of a free drop without friction of 4 cm (± 2.5 %) on a flat floor, and only strike the floor once per fall. They should have a diameter of 3 cm and a spherical end with a radius of about 50 cm.

It is recommended during measurements to use at least 3 positions for the tapping machine and the average sound pressure levels should be determined in frequency bands not more than one octave wide and not less than one third octave wide. Frequency range at least 100–3,200 Hz. In laboratory tests the sound field should be produced in a reverberant room below the test floor.

ISO Recommendation R. 226

Normal equal loudness contours for pure tones and normal threshold of hearing under free-field listening conditions

This recommendation contains a chart of equal loudness contours from 20 to 15,000 Hz (see Fig. 1), a set of rules for where the curves can be applied and two Appendices.

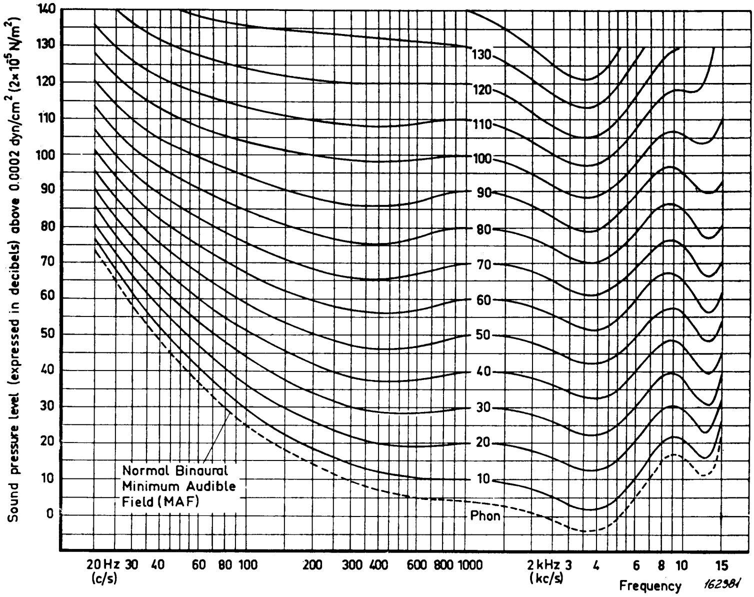


Fig. 1. Normal equal loudness contours for pure tones. They can be applied when:

a) The source of sound is directly ahead of the listener;

b) The sound reaches the listener in the form of a free progressive plane wave;

c) The sound pressure level is measured in the absence of the listener;

d) The listening is binaural;

e) The listeners are otologically normal persons in the age group 18 to 25 years inclusive.

Appendix A gives information on the method of derivation of the equal loudness contours on a mathematical basis, and with the help of tables **Appendix B** gives correction formulae for the age of listeners.

ISO Recommendation R. 266

Preferred frequencies for acoustical measurements

The recommendation contains a table of preferred frequencies of acoustic measurements and does not deal with frequencies for music. As basis for all series of preferred frequencies the frequency 1,000 Hz is chosen because of its great importance in acoustics. Because most commonly a constant percentage increment in frequency is used in

acoustic measurements the present recommendation deals with geometric series and is not intended to apply where a constant frequency increment, or other particular spacing would be more suitable.
In the case of bandpass filters or bands of sound the frequencies listed in the table below should be the geometric center frequencies of the band.

Table of Preferred Frequencies

Preferred frequencies	one oct.	half oct.	third oct.	Preferred frequencies	one oct.	half oct.	third oct.	Preferred frequencies	one oct.	half oct.	third oct.
16	x	x	x	160			x	1600			x
18				180		x		1800			
20			x	200			x	2000	x	x	x
22.4		x		224				2240			
25			x	250	x	x	x	2500			x
28				280				2800		x	
31.5	x	x	x	315			x	3150			x
35.5				355		x		3550			
40			x	400			x	4000	x	x	x
45		x		450				4500			
50			x	500	x	x	x	5000			x
56				560				5600		x	
63	x	x	x	630			x	6300			x
71				710		x		7100			
80			x	800			x	8000	x	x	x
90		x		900				9000			
100			x	1000	x	x	x	10000			x
112				1120				11200		x	
125	x	x	x	1250			x	12500			x
140				1400		x		14000			
160			x	1600			x	16000	x	x	x

ISO Recommendation R. 354

Measurement of absorption coefficient in a reverberation room

The recommendation concerns sound absorption measurements in specially constructed reverberation rooms. The sound absorption takes place partly during the partial reflections at the boundaries of the room and the objects in it, partly during the propagation in air.
If the equivalent absorption area of the empty reverberation room is increased by the additional absorption area, ΔA, of objects brought into the room, then

$$\Delta A = V\,[0.92/c\,(d_2 - d_1) - 4\,(m_2 - m_1)] \qquad (m^2)$$

$$= V\,[55.3/c\,(\frac{1}{T_2} - \frac{1}{T_1}) - 4\,(m_2 - m_1)] \qquad (m^2)$$

where: V = volume of the room (m^3)

c = velocity of sound in air (m/sec)

d_2 = reverberation decay rate after the introduction of the objects (dB/sec)

d_1 = reverberation decay rate before the introduction of the objects (dB/sec)

m_2 = energy attenuation coefficient of the air in the room after the introduction of the objects

m_1 = energy attenuation coefficient of the air in the room before the introduction of the objects

T_2 = reverberation time (sec.) of the room after the introduction of the objects

T_1 = reverberation time (sec.) of the empty room.

The absorption coefficient, α_s, of a plane absorber with the surface area S, is given by: $\alpha_s = \Delta A/S$.
(In the case of a poor absorber it might be necessary to ammend the formula).
Certain requirements are also laid down for the measuring arrangement. The volume of the room should be as close to 200 m^3 as possible, and the shape of the room should be such that $l_{max} < 1.9\ V^{1/3}$, where l_{max} is the greatest straight line which can fit within the boundary. Various methods of obtaining a diffuse sound field are suggested in an appendix (non-parallel boundaries, diffusing elements).

The reverberation time of the empty room should exceed the values of:

T (sec.)	5.0	5.0	5.0	4.5	3.5	2.0
f (Hz)	125	250	500	1000	2000	4000

If the test specimen consists of plane absorbers they should cover a single area, S, between 10 and 12 m^2.
The sound should be generated by loudspeakers, and either third octave (or at most half octave) limited white noise or a warble tone should be used. The frequency deviation of the warble tone should be about ± 10 % of the mean frequency up to 500 Hz, and ± 50 Hz above 500 Hz. A modulation frequency of 6 Hz should be used.

The recording system should consist of a level recorder or cathode ray tube with a logarithmic amplifier, capable of handling decay rates of at least 300 dB/s. It is recommended to include octave, one third or half octave filters in the recording system. Each evaluation of a decay rate or reverberation time for a given frequency band should be based on at least 6 records and the recorded decay curve should be approximated by a straight line in the region from 5 to at least 35 dB below the stationary level.

The measurements should be carried out at least at mean frequencies at octave intervals: 125–250–500–1,000–2,000–4,000, and certain recommendations are given as to the presentation of measurement data and report.

In an Appendix is stated that a room with a volume between 180 m^3 and 100 m^3 may be used, but only for measurements above a limiting frequency defined by:

$$f = 125 \left(\frac{180}{V}\right) \text{ Hz}$$

ISO Recommendation R. 357

Expression of the power and intensity levels of sound or noise

This recommendation is supplementary to ISO recommendation R 131 and defines the sound level of a sound or noise as:

$$10 \log_{10} \frac{p}{p_0} \text{ dB}$$

where p = sound power in question and p_0 = reference sound power = 10^{-12} W = 1 picowatt (pW). Similarly the sound intensity level is defined as:

$$10 \log_{10} \frac{I}{I_0} \text{ dB}$$

where I = sound intensity in question and I_0 = reference sound intensity = 10^{-12} W/m^2 = 1 pW/m^2, also expressed as 10^{-16} W/cm^2.

ISO Recommendation R. 362

Methods of measurement of noise emitted by vehicles

This recommendation is based primarily on a moving vehicle test, the ISO reference test. However, because different practices already exist specifications of two other methods used are also given in an Appendix. For the measurements it is, in all circumstances, recommended to use a precision sound level meter with the weighting network A inserted and meter time constant corresponding to "fast response". Certain recommendations with regard to the use of the instrument are also given. A suitable acoustical environment for the test would consist of an open space of some 50 m radius, of which the central 20 m, for example, would consist of concrete, asphalt or equivalent material. The ambient noise should be such that the reading produced on the meter is at least 10 dB below that produced by the test vehicle. Fig. 1 shows a

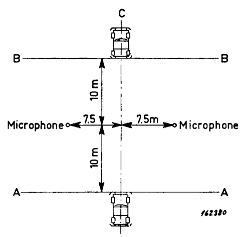


Fig. 1.

sketch of a typical test site. The vehicle should follow the path CC, and the microphone should be located 1.2 m above the ground level. At least 2 measurements are to be made on each side of the vehicle as it passes the measuring positions. The vehicle should be driven in second gear (or third gear if it has more than 4 gears) at a speed corresponding to 3/4 of the maximum engine speed, or at 50 km/h, whichever is the lowest.
In the Appendix a method of measurements with stationary vehicles and also a method of measurements with the vehicle in accelerated motion are given.

ISO Recommendation R. 389

Standard Reference Zero for the calibration of pure-tone audiometers

After defining the terms equivalent threshold sound pressure level and reference threshold sound pressure level (monaural earphone listening) a table is given for the recommended standard values of reference equivalent sound pressure level for constant auditory threshold. As this is dependent on the pattern of the earphone as well as the pattern of the artificial ear employed both the type of earphone and artificial ear used are also stated.

Table. – **Recommended Reference Equivalent Threshold Sound Pressure Levels**

Frequency	Reference equivalent threshold sound pressure levels relative to 2×10^{-5} N/m² (2×10^{-4} dyn/cm²)				
Hz	decibels				
125	44.5	47.5	47	45.5	55
250	27.5	28.5	28	24.5	33
500	11.5	14.5	11.5	11	14.5
1000	5.5	8	5.5	6.5	8.5
1500	4.5	7.5	6.5	6.5	8.5
2000	4.5	8	9	8.5	9
3000	6	6	8	7.5	10.5
4000	8	5.5	9.5	9	11.5
6000	17	8	8	8	18.5
8000	14.5	14.5	10	9.5	9.5
Pattern of earphone	Audio 15	Beyer DT 48	S.T.C. 4026-A	W.E. 705-A	T.D.6
Type of artificial ear or coupler	C.N.E.T. artificial ear	N.B.S. type 9-A coupler (with P.T.B. adapter)	B.S.2042 Fig. 1a, 2b) artificial ear	N.B.S. type 9-A coupler	IU-3 type artificial ear
Country of origin of data	France	Germany	United Kingdom	U.S.A.	U.S.S.R.

ISO Recommendation R. 454

Relation between the loudness of narrow bands of noise in a diffuse-field and in a frontally incident free-field

After having briefly described the importance of establishing a relation between the loudness of diffuse field and frontally incident free-field sounds the conditions of applicability of the figures given in the table below are outlined, i.e.: The sound pressure level should be measured in the absence of the listener, the listening should be binoural, the listeners should be otologically normal persons in the age groups 18–25 and the sound should be narrow bands of noise of less than critical bandwidth.

Table.

Frequency Hz	Difference (dB)
50	0
63	0
80	0
100	0
125	0
160	0
200	0.3
250	0.6
315	0.9
400	1.2
500	1.6
630	2.3
800	2.8
1000	3.0
1250	2.0
1600	0.0
2000	−1.4
2500	−2.0
3150	−1.9
4000	−1.0
5000	0.5
6300	3.0
8000	4.0
10000	4.3

ISO Recommendation No. 507

Procedure for describing aircraft noise around an airport

The purpose of this ISO Recommendation is to provide a means for describing the total noise exposure on the ground around an airport produced by one or a number of aircraft, of the same type or different types, operating under any known set of conditions.

It is stated, however, that the Recommendation does not apply directly to the noise produced by helicopters or vertical take-off flight vehicles.

The Recommendation contains five sections and three annexes, of which the two first sections describe the scope and purpose of the Recommendation.

Section 3 outlines the measurement of aircraft noise received on the ground and is split into a number of subsections. The first of these subsections describes some requirements to be met by the measuring equipment used and states that the noise should be recorded on magnetic tape for later frequency analysis in terms of octave bands. Certain tolerances are given for the frequency response of the complete record-reproduce equipment, including the measuring microphone with wind and rain shield. Provisions for acoustic calibration of the complete equipment are recommended.

The second subsection deals with the acoustical environment, while the third subsection outlines the types of measurements that should be considered.

Two types of measurements are described: measurements of the noise produced by aircraft in flight and of the noise produced by aircraft on the ground.

When measurements are made on the noise from aircraft in flight the fundamental information is the maximum sound pressure level, in octave bands, observed as the aircraft passes directly overhead. Sets of curves should be constructed for various heights of the aircraft and for various operating conditions (take-off: full power, climb power, reduced climb power, landing: maximum and minimum power etc.).

The fundamental noise data should be corrected for temperature, relative humidity conditions and background noise.

When measurements are made on the noise from aircraft on the ground the most important data are the directional characteristics of the noise fields. These should be determined as a function of angle of azimuth around the aircraft, at a distance of 100 m.

Atmospheric as well as aircraft operating conditions during measurement should be stated in all cases.

Section 4 describes the calculation of perceived noise level (PN dB) from measured noise data. This calculation should be performed in three steps:

Step 1. The maximum value of sound pressure level in each octave band (Lp) is converted to a perceived noisiness by means of Table 2 given in Annex B of the Recommendation.

Step 2. The noiseness values, n, found in step 1 are combined according to the formula:

$$N = n_{max} + 0.3\,(\Sigma n - n_{max})$$

where n_{max} is the greatest value of n and Σn is the sum of the noisiness values in all the bands.

Step 3. N is converted into PN dB by means of Table 3 given in Annex B.

Finally, Section 5 contains procedures for describing the noise exposure on the ground in the vicinity of an airport. This section is also split into subsections, the first of which describes the basic construction of noise contour sets for a single aircraft on ground. The contours are based on equal maximum perceived noise levels and can be determined when the following data are available: (a) The engine power used during the operation; (b) The flight path, and (c) The physical data describing the noise produced by the aircraft.

It is recommended that contours of maximum perceived noise level be constructed at successive multiples of 5 PNdB, starting at the 90 PNdB level or lower. Consideration must be given to the local topography of the terrain.

The second subsection considers two basic noise contour sets for a single aircraft in flight, namely the maximum noise produced on ground during (1) take-off operations and (2) landing operations, and specifies the aircraft operating conditions for which these contour sets should be determined.

In subsection three recommendations are given for the determination of a characteristic noise contour set for one or more aircraft in flight, which has a specified statistical relationship to the distribution of aircraft operating conditions.

Subsection four specifies the construction of a basic noise contour set for aircraft operation on the ground, while subsection five*) deals with noise exposure produced by a succession of aircraft operations taking the duration of each operation as well as the number of operations into account. A formula for the construction of equal total noise exposure contours is given:

$$\bar{Q} = k \times \log \frac{1}{T} \sum_{i} Ni \times Ti \times 10^{Li/k}$$

where $\bar{Q}$ = noise exposure index.

Li = maximum perceived noise level ($PNdB_{max}$) of an aircraft operation.

Ti = Duration in seconds during which the recorded signal when passed through weighting network A (IEC Rec. 179) remains within 10 dB of the highest level.

N = number of operations in a specified time interval (e.g. daytime, nightime etc.).

T = specified time interval.

k = 10 (recommended for planning purposes).

Finally, Annex A gives a table for sound attenuation in air, while Annex B gives tables and a chart for the determination of perceived noise level (PNdB) from octave sound pressure level data. The tables are reproduced below.

An appendix, Appendix Z, is added which presents a relevant list of references.

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*) This subsection is subject to revision.

Annex B

Table 2. **Perceived noisiness in noys as a function of sound pressure level.**

	Band centre frequency in Hz							
Lp	63	125	250	500	1000	2000	4000	8000
29							1.0	
30							1.1	
31							1.1	
32						1.0	1.2	
33						1.1	1.3	
34						1.2	1.4	
35						1.3	1.5	
36						1.3	1.6	
37						1.4	1.8	1.0
38						1.5	1.9	1.1
39						1.6	2.0	1.2
40				1.0	1.0	1.7	2.2	1.4
41				1.1	1.1	1.8	2.4	1.5
42				1.1	1.1	2.0	2.6	1.7
43				1.2	1.2	2.2	2.8	1.8
44			1.0	1.3	1.3	2.4	3.0	2.0
45			1.1	1.4	1.4	2.6	3.2	2.2
46			1.2	1.5	1.5	2.8	3.4	2.4
47			1.3	1.6	1.6	3.0	3.6	2.6
48			1.4	1.7	1.7	3.2	3.9	2.8
49			1.5	1.9	1.9	3.4	4.1	3.0
50			1.6	2.0	2.0	3.6	4.4	3.2
51		1.0	1.7	2.1	2.1	3.9	4.7	3.4
52		1.1	1.9	2.3	2.3	4.1	5.0	3.6
53		1.2	2.0	2.5	2.5	4.4	5.3	3.9
54		1.3	2.1	2.6	2.6	4.7	5.7	4.1
55		1.4	2.3	2.8	2.8	5.0	6.1	4.4
56		1.5	2.4	3.0	3.0	5.3	6.5	4.7
57		1.7	2.6	3.2	3.2	5.7	7.0	5.0
58		1.8	2.8	3.5	3.5	6.1	7.5	5.3
59		2.0	3.0	3.7	3.7	6.5	8.0	5.7
60	1.0	2.2	3.2	4.0	4.0	7.0	8.7	6.1
61	1.1	2.4	3.5	4.3	4.3	7.5	9.3	6.5
62	1.2	2.6	3.7	4.6	4.6	8.0	10	7.0
63	1.3	2.8	4.0	4.9	4.9	8.7	11	7.5
64	1.5	3.0	4.3	5.3	5.3	9.3	11	8.0
65	1.6	3.2	4.6	5.7	5.7	10	12	8.7
66	1.8	3.5	5.0	6.1	6.1	11	13	9.3
67	2.0	3.7	5.4	6.5	6.5	11	14	10
68	2.2	4.0	5.9	7.0	7.0	12	15	11
69	2.3	4.3	6.4	7.5	7.5	13	16	11
70	2.5	4.6	6.9	8.0	8.0	14	17	12
71	2.8	5.0	7.5	8.6	8.6	15	19	13
72	3.0	5.4	8.0	9.2	9.2	16	20	14
73	3.3	5.9	8.7	9.8	9.8	17	21	15
74	3.7	6.4	9.3	10.6	10.6	19	23	16

contd.

Band centre frequency in Hz								
Lp	63	125	250	500	1000	2000	4000	8000
75	4.1	6.9	10	11.3	11.3	20	24	17
76	4.5	7.5	11	12	12	21	26	19
77	5.0	8.3	11	13	13	23	28	20
78	5.4	9.1	12	14	14	24	30	21
79	5.9	10	13	15	15	26	32	23
80	6.4	11	14	16	16	28	35	24
81	6.9	11	15	17	17	30	37	26
82	7.5	12	16	18	18	32	40	28
83	8.3	13	17	20	20	35	42	30
84	9.1	14	19	21	21	37	45	32
85	10	15	20	23	23	40	47	35
86	12	16	21	24	24	42	50	37
87	13	17	23	26	26	45	55	40
88	13	19	24	28	28	47	60	42
89	14	20	26	30	30	50	63	45
90	15	21	28	32	32	55	67	47
91	16	23	30	34	34	60	71	50
92	17	24	32	37	37	63	75	56
93	19	26	35	39	39	67	80	60
94	20	28	37	42	42	71	86	63
95	21	30	40	45	45	75	93	67
96	23	32	42	49	49	80	100	71
97	24	35	45	52	52	86	108	75
98	26	37	47	56	56	93	116	80
99	28	40	50	60	60	100	125	86
100	30	42	55	64	64	108	133	93
101	32	45	60	69	69	116	142	100
102	35	47	64	74	74	125	150	108
103	37	50	69	79	79	133	162	116
104	40	55	74	84	84	142	173	125
105	42	60	79	91	91	150	186	133
106	45	64	84	97	97	162	200	142
107	47	69	91	104	104	173	215	150
108	50	74	97	111	111	186	232	162
109	55	79	104	119	119	200	250	173
110	60	84	111	128	128	215	266	186
111	64	91	119	137	137	232	284	200
112	69	97	128	147	147	250	300	215
113	74	104	137	158	158	266	324	232
114	79	111	147	169	169	284	346	250

Table 3. **Perceived noise level as a function of total perceived noisiness.**

N				N			
Lower	Mid	Upper	PNdB	Lower	Mid	Upper	PNdB
1.0	1.0	1.0	40	43.8	45.2	46.8	95
1.1	1.1	1.1	41	46.9	48.5	50.2	96
1.1	1.1	1.2	42	50.3	52.0	53.8	97
1.2	1.2	1.3	43	53.9	55.7	57.7	98
1.3	1.3	1.4	44	57.8	59.7	61.8	99
1.4	1.4	1.5	45	61.9	64.0	66.3	100
1.5	1.5	1.6	46	66.4	68.6	71.0	101
1.6	1.6	1.7	47	71.1	73.5	76.1	102
1.7	1.7	1.8	48	76.2	78.8	81.6	103
1.9	1.9	1.9	49	81.7	84.4	87.4	104
2.0	2.0	2.1	50	87.5	90.5	93.7	105
2.1	2.1	2.2	51	93.8	97.0	100.4	106
2.3	2.3	2.4	52	100.5	104.0	107.6	107
2.5	2.5	2.5	53	107.7	111.4	115.3	108
2.6	2.6	2.7	54	115.4	119.4	123.6	109
2.8	2.8	2.9	55	123.7	128.0	132.5	110
3.0	3.0	3.1	56	132.6	137.2	142.0	111
3.2	3.2	3.4	57	142.1	147.0	152.2	112
3.5	3.5	3.6	58	152.3	157.6	163.1	113
3.7	3.7	3.9	59	163.2	168.9	174.8	114
4.0	4.0	4.1	60	174.9	181.0	187.4	115
4.2	4.3	4.4	61	187.5	194.0	200.8	116
4.5	4.6	4.7	62	200.9	207.9	215.3	117
4.8	4.9	5.1	63	215.4	222.8	230.7	118
5.2	5.3	5.5	64	230.8	238.8	247.3	119
5.6	5.6	5.8	65	247.4	256.0	265.0	120
5.9	6.1	6.3	66	265.4	274.4	284.0	121
6.4	6.5	6.7	67	284.1	294.0	304.4	122
6.8	7.0	7.2	68	304.5	315.2	326.3	123
7.3	7.5	7.7	69	326.4	337.8	349.7	124
7.8	8.0	8.3	70	349.8	362.0	374.8	125
8.4	8.6	8.9	71	374.9	388.0	401.7	126
9.0	9.2	9.5	72	401.8	415.8	430.5	127
9.6	9.8	10.2	73	430.6	445.7	461.4	128
10.3	10.6	10.9	74	461.5	477.7	494.5	129
11.0	11.3	11.7	75	494.6	512.0	530.0	130
11.8	12.1	12.5	76	530.1	548.7	568.2	131
12.6	13.0	13.5	77	568.2	588.1	608.9	132
13.6	13.9	14.4	78	609.0	630.3	652.6	133
14.5	14.9	15.4	79	652.7	675.5	699.4	134
15.5	16.0	16.6	80	699.5	724.1	749.6	135
16.7	17.1	17.7	81	749.7	776.0	803.3	136
17.8	18.4	19.0	82	803.4	831.7	861.1	137
19.1	19.7	20.4	83	861.2	891.4	922.9	138
20.5	21.1	21.8	84	923.0	955.4	989.1	139
21.9	22.6	23.4	85	989.2	1024.0	1060.1	140
23.5	24.2	25.1	86	1060.2	1097.5	1136.1	141
25.2	26.0	26.9	87	1136.2	1176.2	1217.7	142
27.0	27.8	28.8	88	1217.8	1260.6	1305.1	143
28.9	29.8	30.9	89	1305.2	1351.1	1398.8	144
31.0	32.0	33.1	90	1393.9	1448.2	1499.1	145
33.2	34.3	35.5	91	1499.2	1552.1	1606.7	146
35.6	36.8	38.1	92	1606.8	1663.4	1722.1	147
38.2	39.4	40.8	93	1722.2	1782.8	1845.7	148
40.9	42.2	43.7	94	1845.8	1910.7	1978.2	149

ISO Recommendation R. 532

Procedure for calculating loudness level

This ISO Recommendation contains ten sections and specifies two methods of calculating the loudness or loudness level of a complex sound. Section one describes briefly the basic differences between the two methods while section two describes terms common to both.

Sections 3–6 then describe "Procedure A for Calculating Loudness of a Complex Sound that has been Analyzed in Terms of Octave Bands". Here each octave band sound pressure level is converted into a loudness index by means of the curves shown in Fig. A. In the figure the frequency axis is marked in terms of band center frequencies. The various loudness indices found in this way for the sound spectrum are summed by means of the formula:

$$S_t = S_m + F(\Sigma S - S_m)$$

where F = 0.3 for octave band sound spectra.

S_m is the greatest of the loudness indices and ΣS is the sum of the loudness index by means of the curves shown in Fig. A. In the figure (OD)*). By applying the nomographic scales to the right in Fig. A the total loudness in sones (OD) can be converted into a total loudness level in phones (OD).

Method A, as outlined above, is applicable only when the sound spectrum is relatively smooth and the sound is more or less steady and contains no pure tone. Also, the method should only be used when the sound field is diffuse and the sound is measured by means of an omnidirectional microphone.

Although Method A is based on the use of octave band sound pressure level data it has also been applied to analysis made in terms of half-octaves and third-octaves and may be so used if the above requirements to the type of sounds and sound fields are fulfilled.

In such cases the value of F should be:

Half-octave : F = 0.2, Third-octave : F = 0.15.

Sections 7–10 describe "Procedure B for Calculating the Loudness of a Complex Sound that has been Analyzed in Terms of One-third Octave Bands". This procedure is applicable to sounds with strong line spectra or irregular spectra for which octave-band analyses are not appropriate. It consists in, by means of a set of graphs, transforming third-octave band data into parts of an area which corresponds to parts of the loudness. The total loudness level in phons (GF or GD)**) is calculated from the total area and is read from a scale (see also Fig. B).

To perform the actual calculations three steps are recommended:

Step 1 consists in selecting the appropriate graph and plotting the measured third octave data onto the graph. The correct graph is selected by considering wheter the sound field being explored is of the

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*) (OD) stands for: **O**ctave bands, **D**iffuse sound.

) GF stands for "G**ruppen" (= critical bands, **F**rontal sound.
GD stands for "**G**ruppen", **D**iffuse sound.

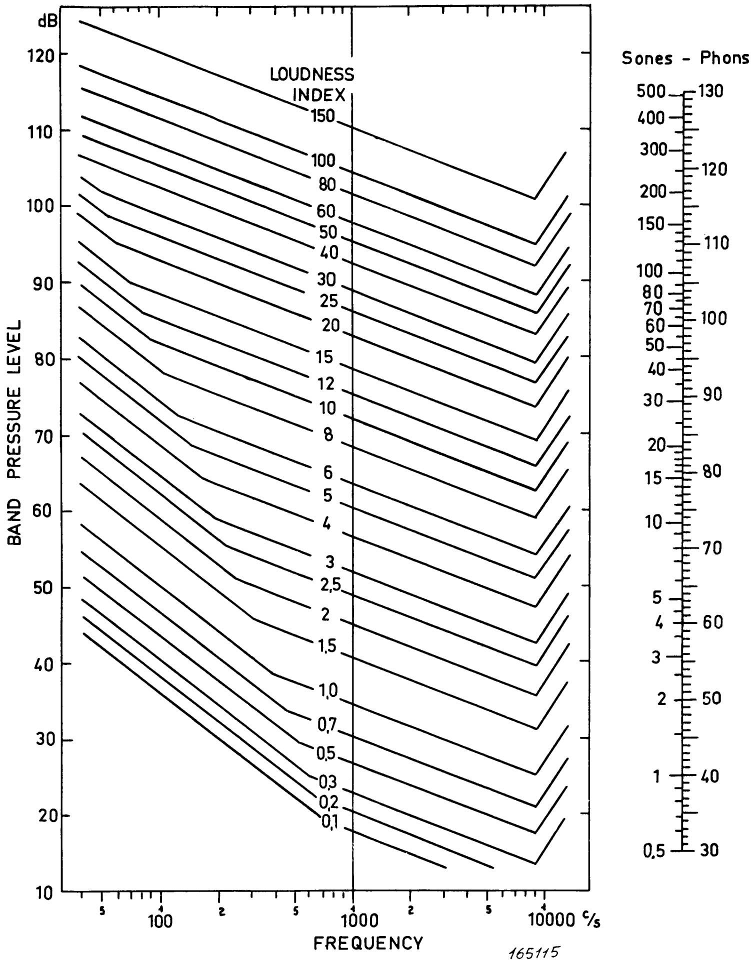


Fig. A. Contours of equal loudness index.

free-field type (frontal sound) or of the diffuse field type, and then chosing the corresponding chart which includes the highest third-octave band level measured. For one third octave bands higher than 280 Hz (band center frequency 315 Hz) the band levels can be directly plotted on the chart. However, due to the fact that the critical bands in hearing have bandwidths which below 280 Hz are wider than one third octave the third octave band levels are in this frequency grouped and combined before they are entered on the chart:

(I) Combine all bands up to the cut-off frequency of 90 Hz (L_1).

(II) Combine the three bands from 90 to 180 Hz (L_2).

(III) Combine the two bands from 180 to 280 Hz (L_3).

The rule of combining is the power-law for instance:

$$L_2 = 10 \log_{10} \left(\text{antilog} \frac{L_{100}}{10} + \text{antilog} \frac{L_{125}}{10} + \text{antilog} \frac{L_{160}}{10}\right)$$ where L_{100} etc. is

the measured third-octave band pressure level for the band with center frequency 100 Hz.

Step 2 consists in connecting the band level-lines as follows (Fig. B): When the level in the next higher frequency band is higher, a vertical line is drawn between the two levels, while when the level on the next higher band is lower, the connection between the to band levels is made by means of a downward sloping curve interpolated between the dashed curves on the graph.

Step 3 consists in transforming the area enclosed by the stepped curve into a rectangle of the same area and having a base equal to the width of the graph, either by eye or by means of a planimeter. The height of the rectangle gives directly the loudness level in phons (GD or GF) or the loudness in sones (GD or GF) from the scales on the side of the graph (Fig. B).

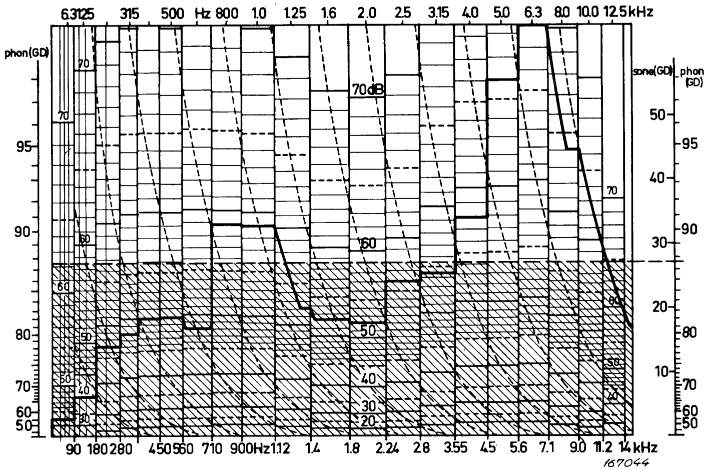


Fig. B. Example illustrating the calculation of loudness and loudness level according to produce B. The total loudness was here approximately 28 sones (GD) and the corresponding loudness level 87.5 phons (GD). (This example is not included in the ISO Recommendation).

Draft ISO Recommendation No. 695

General Requirements for the preparation of test codes for measuring the noise emitted by machines

The Draft Recommendation contains seven sections and four annexes. While the first three sections describe the scope of the Recommendation and the definitions and terms used the fourth and fifth sections briefly outline the installation and operation of the machine to be tested as well as the quantities to be measured.

It is stated that one or both of the following measurements should be made:

(a) Sound level (weighting network A)

(b) Sound pressure level in frequency bands of given width, preferably octave bands.

Section six recommends the methods of measurement and is split into four subsections, the first of which outlines the methods of determination of the sound power.

The first of these concerns hemispherical radiation and free-field methods. It is stated that the measurement points should be sufficiently remote from the machine for conditions of propagation of progressive sound waves to be established and there should be no reflected waves at the measurement points.

The formulae used for the determination of sound power and directivity index under hemispherical conditions are given in Annex A. In the use of sound power determination the formula to be used is:

$$10 \log_{10} \frac{p}{P_o} = 20 \log_{10} \frac{p_m}{p_o} + 10 \log_{10} \frac{2 \pi r^2}{S_o}$$

where

$10 \log_{10} \frac{P}{P_o}$ is the sound power level of the machine above P_o

$20 \log_{10} \frac{p_m}{p_o}$ is the mean sound pressure level above p_o

$2 \pi r^2$ is the surface of the test hemisphere above $S_o = 1$ m^2

P_o is the reference sound power level $= 10^{-12}$ W
p_o is the reference sound pressure level $= 2 \times 10^{-5}$ N/m^2 =
(2×10^{-4} dyn/cm^2)

When the machine is not mounted on a reflecting plane but is in free space the radiation becomes spherical and not hemispherical and $2 \pi r$ should be replaced by $4 \pi r^2$.

The directivity index (DI) under hemispherical radiation conditions can be calculated from the formula:

$$DI = 20 \log_{10} \frac{p}{p_o} - 20 \log_{10} \frac{p_m}{p_o} + 3 \text{ dB}$$

where $20 \log_{10} \frac{p}{p_o}$ is the sound pressure level above p_o and

$20 \log_{10} \frac{p_m}{p_o}$ is the mean sound pressure level above p_o

In cases of spherical and not hemispherical radiation from the machine the 3 dB in the above equation should be omitted.

The second method is termed the diffuse field method and recommends the use of a highly reverberant enclosure. A formula from which the sound power can be calculated in this case is given in Annex B.

$$10 \log_{10} \frac{P}{P_o} = 20 \log_{10} \frac{p_m}{p_o} - 10 \log_{10} \frac{T}{T_o} + 10 \log_{10} \frac{V}{V_o} - 14 \text{ dB.}$$

In the formula P, P_o p_m and p_o describe the quantities as defined above,
T is the reverberation time of the enclosure in seconds
$T_o = 1$ second
V is the volume of the room in m^3
$V_o = 1\ m^3$
This method can provide no information on the directivity of the acoustic radiations.
Finally, a third method, the semi-reverberant method is outlined and a relevant formula for acoustic power level calculations stated in Annex C:

$$10 \log_{10} \frac{P}{P_o} = 10 \log_{10} \frac{P_r}{P_o} + 20 \log_{10} \frac{p_m}{p_o} - 20 \log_{10} \frac{p_{mr}}{p_o}$$

This method requires the use of a reference sound source of known acoustic power, P_r, which is substituted for the machine under test. The sound pressure p_{mr} then is the mean sound pressure level obtained when the reference sound source is switched on, and the sound pressure, p_m, is, as above, the mean sound pressure when the machine is operating (and the reference sound source is switched off).

In subsection 6.2 a method of near-field sound pressure level measurements and evaluation is described, using a concept termed prescribed surface. The prescribed surface is an hypothetical surface surrounding the machine which is sufficiently close to the machine so that sound pressure level measurements on this surface are not significantly affected by close reflecting surfaces or background noise. The sound pressure level at a reference radius can then be calculated according to the formula (Annex D):

$$20 \log_{10} \frac{p_d}{p_o} = 20 \log_{10} \frac{p_m}{p_o} - 20 \log_{10} \frac{d}{r}$$

where

$20 \log_{10} \frac{p_d}{p_o}$ is the sound pressure level above p_o at the reference radius, d(m)
p_m is the mean sound pressure over the prescribed surface, and
$r = \sqrt{\frac{S}{2\pi}}$ where S is the area of the prescribed surface (m^2)
$p_o = 2 \times 10^{-5}$ (as defined above).

Preferred values of d are 1, 3 or 10 m. It is specifically stated that only in certain cases is it possible from these measurements to arrive at an approximate evaluation of the sound power starting from the sound pressure level at the reference radius, d, defined above.

Subsection 6.3 discusses the effects of background noise and states that measurement readings with the machine on test ought to exceed those due to background noise alone by at least 10 dB. If the difference in readings is less than 3 dB measurements in general cease to have any significance. For differences between 10 dB and 3 dB corrections should be applied to the measured results.

In subsection 6.4 the choice of method is discussed and it is recommended to use methods of measurement of sound pressure level under conditions that permit the determination of acoustic power.

The last section of the Recommendation discusses the presentation of results and gives a list of the information necessary for a complete evaluation of measurements.

Draft ISO Recommendation No. 880

Rating of sound insulation for dwellings

This Draft Recommendation describes a method of evaluating the airborne and impact sound insulation for dwellings when the results of measurements made by the method described in ISO R 140 are available. A single set of reference values should be used for comparing with the measured results.

In the case of airborne sound insulation the reference values are shown in Fig. 1.

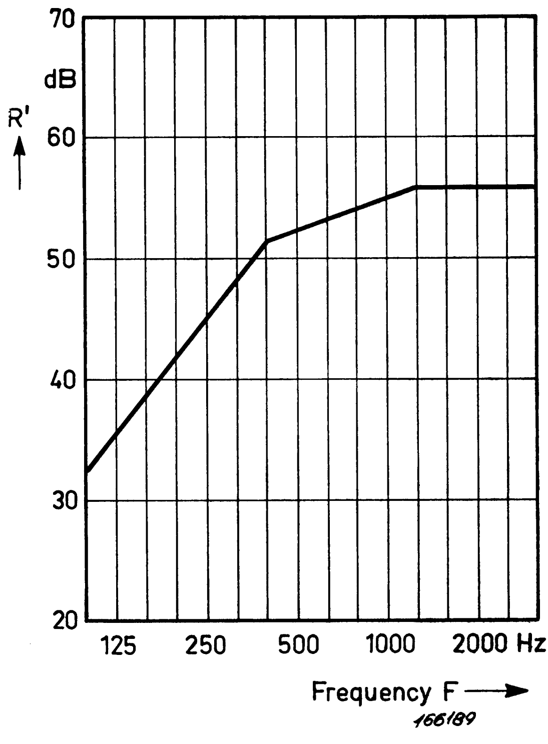


Fig. 1.

In the case of impact sound levels the reference values are shown in Fig. 2 below.

To compare the measured values the reference curve is shifted in steps of 1 dB towards the measured curve until the following conditions are satisfied:

Either the mean unfavourable deviation, computed by dividing the sum of the unfavourable deviations by the total number of measuring frequencies, is greater than + 1 dB but not more than 2 dB, or the mean unfavourable deviation is less than 2 dB and the maximum unfavourable deviation at any frequency does not exceed 8 dB for measurements in third octave bands or 5 dB for measurements in octave bands.

From this shift in reference curve an Airborne Sound Insulation Index Ia and an Impact Sound Level Index Ic are defined as the values of the shifted curves at 500 Hz.

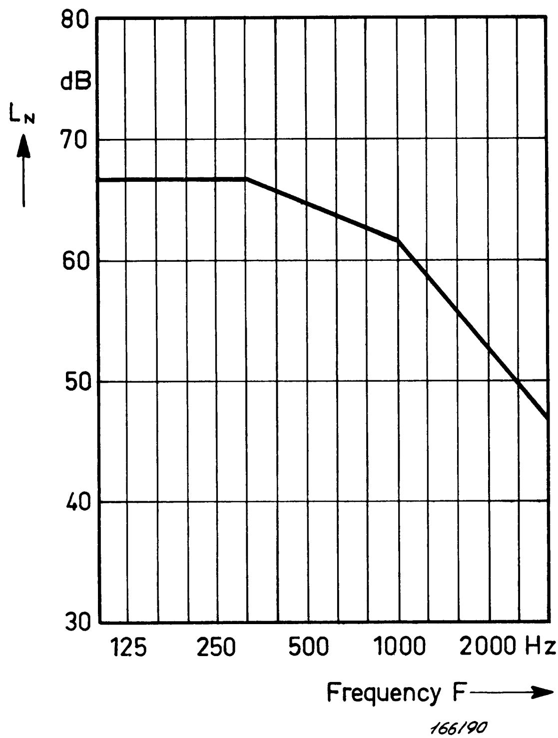


Fig. 2.

National and International Standards arranged according to subjects

On the following pages standards and recommendations related to acoustic noise measurements have been listed.

The various standards have been grouped according to subjects:

A. General.
B. Noise Rating Recommendations.
C. Noise Measuring Equipment.
D. Measurement of Noise emitted by Machines.
E. Measurement of Noise Transmission Loss in Buildings.
F. Measurement of Vehicle and Traffic Noise.

A. General

Country	Identification of Standard	Contents of Standard	Issuing Institution
Austria	**ÖAL-Richtlinie Nr. 3**	Schalltechnische Grundlagen für die Beurteilung von Lärmbelästigungen.	Österreichischen Arbeitsring für Lärmbekämpfung, Regierungsgebäude, 1012 Wien.
Belgium	**NBN576.02-1961 25 F**	Niveaux Physiques et subjectif d'un son ou d'un bruit et échelle de sonie.	Institut Belge de Normalisation. 29 av. de la Brabançonne Bruxelles 4.
	NBN576.03-1961 55 F	Les lignes isosoniques normales pour sons pour écoutes en champ libre et le seuil d'audition binauriculaire en champ libre.	
C.S.S.R.	**ČSN 01 1304**	Quantities, units and symbols of acoustics.	Office for Standards and Measurements. Praha 1 - Nové Město, Václavské Náměstí 19.
	ČSN 01 1607	Loudness and loudness level of sound.	
	ČSN 368820	Objective methods for noise measurements.	

Country	Identification of Standard	Contents of Standard	Issuing Institution
France	**S 30-003**	Lignes isosoniques Normales pour Sons Purs Ecoutes en Champ Libre et Seuil d'Audition Binauriculaire en Champ Libre.	L'Association Française de Normalisation. 19, rue du 4-Septembre, Paris - 2e.
	S 30-004	Expression des Caractéristiques Physiques et des Caractéristiques Psycho-Physiologiques d'un Son ou d'un Bruit.	
	S 30-005	Mśthode de Calcul du Niveau d'Isosonie.	
Germany (D.B.R.)	**DIN 1318**	Lautstärke, Begriffsbestimmungen.	Beuth-Vertrieb GmbH. Berlin W15 und Köln.
	DIN 45630	Grundlagen der Schallbewertung.	
	DIN 45631	Berechnung des Lautstärke-Pegels aus dem Geräusch-Spektrum.	
	VDL 2058	Beurteilung und Abwehr von Arbeitslärm.	
Great Britain	**B.S. 2497: 1954**	The normal threshold of hearing for pure tones by earphone listening.	British Standards Institution. 2 Park Street, London W. 1.
	B.S. 3045: 1958	The relation between the sone scale of loudness and phone scale of loudness level.	
	B.S. 3383: 1961	Normal equal loudness contours for pure tones and normal threshold of hearing under free-field listening conditions.	
	B.S. 3593: 1963	Recommendation on preferred frequencies for acoustical measurements.	
Hungary	**M. Sz. 3391-51** **M. Sz. 3391-60**	Akustische Grundbegriffe und Formeln.	Magyar Szabványügyi Hivatal. Budapest IX, Üllöi út. 25.
	M. Sz. 3392-54	Akustische Messungen.	
Switzerland	—	»Lärmbekämpfung in der Schweiz«.	Eidgenössische Drucksachen und Materialzentrale. Bern 3.
U.S.A.	**S1. 2-1962**	Method for physical measurement of sound.	United States of America Standards Institute. 10 East 40th Street, New York, N.Y. 10016.
	S1. 6-1960	Preferred frequencies for acoustical measurements.	
	S3. 4	Procedure for the Computation of the loudness of noise.	

Country	Identification of Standard	Contents of Standard	Issuing Institution
International (I.S.O.)	**R. 131**	Expression of the physical and subjective magnitudes of sound or noise.	International Organization for Standardization. 1, Rue de Varefbé, Geneva. Switzerland.
	R. 226	Normal equal loudness contours for pure tones and normal threshold of hearing under free-field listening conditions.	
	R. 266	Preferred frequencies for acoustical measurements.	
	R. 357	Expression of the power and intensity levels of sound or noise.	
	R. 454	Relation between the loudness of narrow bands of noise in diffuse-field and in a frontally incident free-field.	
	R. 532	Procedure for calculating Loudness Level.	

B. Noise Rating Recommendations

Country	Identification of Standard	Contents of Standard	Issuing Institution
Austria	**Bundesgesetzblatt 288**	Kraftfahrverordnung 1955.	Staatsdruckerei, Wien.
	Bundesgesetzblatt 103	Seenverkehrsordnung 1961.	
C.S.S.R.	**ČSN 730531**	Protection against noise transmission in buildings.	Office for Standards and Measurements. Praha 1 - Nové Město, Václavské Náměstí 19.
Great Britain	**B.S. 4142: 1967**	Method of rating industrial noise affecting mixed residential and industrial areas.	British Standards Institution. 2 Park Street, London W. 1.
Hungary	**SZOT 6/1965 (IV)**	Verordnungen des Landesrates der Gewerkschaften.	Magyar Szabványügyi Hivatal. Budaest IX, Üpllöi út. 25.
South Africa	**SABS 083-1962**	Code of practice for the rating of noise for hearing conservation.	South African Bureau of Standards. 55 Visagie Street, Pretoria.
Switzerland	—	»Lärmbekämpfung in der Schweiz«	Eidgenössische Drucksachen und Materialzentrale. Bern 3.
U.S.A.	**S3. 1-1960**	Criteria for background noise in audiometer rooms.	United States of America Standards Institute. 10 East 40th Street, New York, N.Y. 10016.

C. Noise Measuring Equipment

Country	Identification of Standard	Contents of Standard	Issuing Institution
Australia	**AS Z37-1967**	Sound Level Meters Type 1 - General Purpose.	Standards Association of Australia. Science House. 157 Gloucester Street. Sydney.
	AS Z38-1967	Sound Level Meters Type 2 - Precision.	
Belgium	**NBN576. 80-1962 60 F**	Sonomètre de précision.	Institut Belge de Normalisation. 29 av. de la Brabançonne. Bruxelles 4.
C.S.S.R.	**ČSN 356870**	Sound level meter and band pass filter.	Office for Standards and Measurements. Praha 1 - Nové Město, Václavské Náměstí 19.
France	**S 30-002**	Fréquences Normales pour les Mesures Acoustique.	L'Association Française de Normalisation. 19, rue du 4-Septembre. Paris - 2e.
	S 31-005	Sonomètres d'Usage Courant.	
Germany (D.B.R.)	**DIN 5045**	Meßgerät für DIN-Lautstärken Richtlinien.	Beuth-Vertrieb GmbH. Berlin W15 und Köln.
	DIN 45633	Präzisionsschallpegelmesser Anforderungen.	
Germany (D.D.R.)	**TGL 200-7755**	Geräte zur Messung des Schall-druckpegels.	Amt für Standardisierung. Mohrenstrasse 37a, Berlin W. 8.
Great Britain	**B.S. 3489: 1962**	Sound level meters. (industrial grade).	British Standards Institution. 2 Park Street, London W. 1.
	B.S. 3539: 1962	Sound level meters for the measurements of noise emitted by motor vehicles.	
U.S.A.	**S1. 4-1961**	Specification for general purpose sound level meters.	United States of America Standards Institute. 10 East 40th Street, New York N.Y. 10016.
	Z24. 10-1953	Specification for an Octaveband filter set for analysis of noise and other sounds.	
	S1. 11-1966	Octave, half-octave and one-third octave filter sets.	
International (I.E.C.) (I.S.O.)	**IEC-123**	Recommendation for sound level meters.	International Organization for Standardization. 1, Rue de Varembé, Geneva. Switzerland.
	IEC-179	Specification for precision sound level meters.	

D. Measurements of Noise Emitted by Machines

Country	Identification of Standard	Contents of Standard	Issuing Institution
Austria	**ÖAL-Richtlinie Nr. 1**	Messung des Geräusches von Maschinen.	Österreichischen Arbeitsring für Lärmbekämpfung. Regierungsgebäude, 1012 Wien.
Belgium	**NBN 263-1951**	Conditions acoustiques de travail d'installations de chauffage, ventilation, etc.	Institut Belge de Normalisation. 29 av. de la Brabançonne. Bruxelles 4.
C.S.S.R.	**ČSN 123062**	Measurement of noise and vibration from ventilators.	Office for Standards and Measurements. Praha 1 - Nové Město, Václavské Náměstí 19.
	ČSN 178055	Measurement of noise emitted by computers.	
	ČSN 350000	Measurement of noise emitted by electrical machines.	
France	**S 30-006**	Règles Générales pour la Rédaction des Codes d'Essais Relatifs a la Mesure du Bruit Émis par les Machines.	L'Association Française de Normalisation. 19, rue du 4-Septembre, Paris - 2e.
	S 31-006	Code d'Essais pour la Mesure du Bruit Émis par les Machines Électriques Tournantes.	
Germany (D.B.R.)	**DIN 9756**	Lautstärkemessung an Rechenmaschinen.	Beuth-Vertrieb GmbH. Berlin W15 und Köln.
	DIN 42540	Geräuschstärke von Transformatoren; Bewerteter Schalldruckpegel (Schallpegel).	
	DIN 45632	Geräuschmessung an elektrischen Maschinen, Richtlinien.	
Germany (D.D.R.)	**TGL 39-440**	Prüfvorschriften für Fahrzeuggetriebe.	Amt für Standardisierung. Mohrenstrasse 37a, Berlin W. 8.
	TGL 39-703	Prüfvorschriften, Auspuffgeräuschdämpfer, Verbrennungsmotoren.	
	TGL 39-767	Verbrennungsmotoren, Geräuschmessungen, Meßverfahren.	
	TGL 50-29034	Geräuschmessungen an rotierenden elektrischen Maschinen, Richtlinien.	
	TGL 153-6011	Wälslager, Laufgeräusch, Meßverfahren (Entwurf).	
	TGL 153-6012	Wälzlager, (Radial-) Rillenkugellager, Laufgeräusch, zulässige Werte (Entwurf).	
	TGL 200-4504	Elektrische Hausgeräte, Geräuschmessungen, Meß- und Prüfverfahren.	
International (I.S.O.)	**R. 495**	General Requirements for the Preparation of Test Codes for Measuring the Noise Emitted by Machines.	International Organization for Standardization. 1, Rue de Varembé. Geneva, Switzerland.

E. Measurements of Noise Transmission Loss in Buildings

Country	Identification of Standard	Contents of Standard	Issuing Institution
Austria	**ÖNORM B8115**	»Hochbau, Schallschutz und Hörsamkeit«.	Österreichischen Normenausschuss. Bauernmarkt 13, 1010 Wien.
Belgium	**NBN576. 06-1963 20 F**	Mesure «in situ» de l'isolement acoustique aux sons aériens.	Institut Belge de Normalization. 29 av. de la Brabançonne. Bruxelles 4.
C.S.S.R.	**ČSN 358840**	Measurement of sound insulating properties of building structures.	Office for Standards and Measurements. Praha 1 - Nové Město, Václavské Náměstí 19.
France	**S 31-002**	Mesure, en Laboratoire et sur Place, de la Transmission des Sons Aériens et des Bruits de Chocs dans les Constructions.	L'Association Française de Normalisation. 19, rue du 4-Septembre, Paris - 2e.
Germany (D.D.R.)	**TGL 10687**	Bauphysikalische Schutzmaßnahmen, Schallschutz.	Amt für Standardisierung. Mohrenstrasse 37a, Berlin W. 8.
Great Britain	**B.S. 2750: 1956**	Recommendation for field and laboratory measurement of airborne and impact sound transmission in buildings.	British Standards Institution. 2 Park Street, London W. 1.
Hungary	**M.E.-83-65**	Technische Vorschriften des Ministeriums für Bauwesen.	Magyar Szabványügyi Hivatal. Budapest IX, Üllöi út. 25.
Netherlands	**NEN 1070**	Sound insulation measurement in dwellings.	Nederlands Normalisatie-Instituut. Polakweg 5, Ryjswyjk (ZH).
Sweden	**SIS 025251**	Bestämning af ljudisolering. (Measurements of sound insulation).	Sveriges Standardiseringskommission. Stockholm.
U.S.A.	**Z24. 19-1957**	Laboratory Measurement of Airborne sound transmission loss of building floors and walls.	United States of America Standard Institute. 10 East 40th Street, New York, N.Y. 10016.
International (I.S.O.)	**R. 140**	Field and laboratory measurements of airborne and impact sound transmission.	International Organization for Standardization. 1, Rue de Varembé. Geneva. Switzerland.

F. Measurement of Vehicle and Traffic Noise

Country	Identification of Standard	Contents of Standard	Issuing Institution
Austria	**ÖAL-Richtlinien Nr. 2**	Messung des Geräusches von Kraftfahrzeugen.	Österreichischen Arbeitsring für Lärmbekämpfung. Regierungsgebäude, 1012 Wien.
Belgium	**NBN576. 30-1962 35 F**	Methode de mesure du niveau des bruits émis par les véhicles.	Institut Belge de Normalisation. 29 av. de la Brabançonne. Bruxelles 4.
C.S.S.R.	**ČSN 090862**	Noise of Diesel engines. Method of measurement.	Office for Standards and Measurements. Praha 1 - Nové Město, Václavské Náměstí 19.
	ČSN 300512	Measurement of noise emitted by road motor vehicles.	
	ČSN 300513	Measurement of internal noise emitted by road motor vehicles.	
France	**S 31-007**	Mesure du Bruit Product par les Véhicules Automobiles.	L'Association Française de Normalisation. 19, rue du 4-Septembre. Paris - 2e.
Great Britain	**B.S. 3425: 1961**	Measurement of noise emitted by motor vehicles.	British Standards Institution. 2 Park Street, London W. 1.
India	**IS: 3028-1965**	Method of measurement of noise emitted by motor vehicles.	Indian Standards Institution. Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Dehli 1.
New Zealand	**NZSS 1726**	Measurement of noise emitted by motor vehicles.	
South Africa	**SABS 097-1965**	Code of practice for the measurement and limitation of noise emitted by motor vehicles.	South African Bureau of Standards. 55 Visagie Street, Pretoria.
Switzerland	—	»Lärmbekämpfung in der Schweiz«.	Eidgenössische Drucksachen und Materialzentrale. Bern 3.
International (I.S.O.)	**R. 392**	Methods of measurement of noise emitted by vehicles.	International Organization for Standardization. 1, Rue de Varembé. Geneva. Switzerland.
	R. 507	Procedure for describing noise around an airport.	

Practical Formulae and Curves

Acoustic Room Resonances

The total number of room resonances (Eigentones, natural oscillations) occurring in a rectangular room in the frequency range 0 to f is:

$$Q = \frac{4\pi V}{3} \times \left(\frac{f}{c}\right)^3 + \frac{\pi S}{4} \times \left(\frac{f}{c}\right)^2 + \frac{L}{2} \times \left(\frac{f}{c}\right) \quad (1)$$

where:

V = room volume = $l_x \times l_y \times l_z$ [m³]

S = room surface = $2(l_x \times l_y + l_y \times l_z + l_z \times l_x)$ [m²]

L = room edges = $l_x + l_y + l_z$ [m]

c = velocity of sound [m/s]

In a narrow frequency band, Δf, around f the number of resonances are:

$$\Delta Q = \left(\frac{4\pi V}{c^3} \times f^2 + \frac{\pi S}{2c^2} \times f + \frac{L}{2c}\right)\Delta f \quad (2)$$

except at low frequencies where $\Delta Q = Q_{f2} - Q_{f1}$ which should then be calculated directly from formula (1) above.

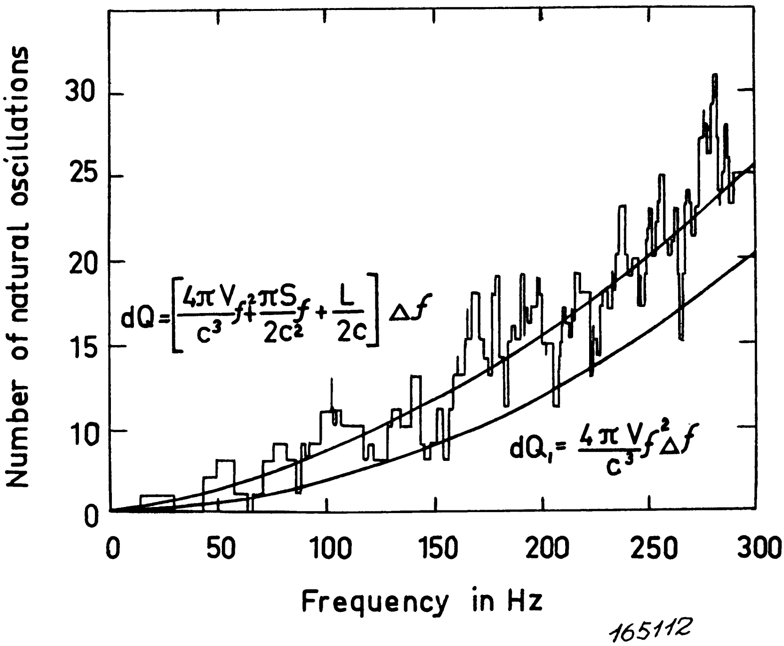


Fig. 1. Comparison between actual number of natural oscillations and the formula for a room with edge lengths 2 × 3 × 6 m³, calculated for a band width of 15 Hz (Bolt).

Very often the approximation

$$\Delta Q \sim \frac{4\pi V}{c^3} \times f^2 \times \Delta f \qquad (3)$$

is used, and it is readily seen that even in very narrow frequency bands the number of room resonances at higher frequencies is very large, see curves in Fig. 1.

Addition and Subtraction of Noise and Vibration Levels in Decibels

a) *Addition.*

If two different bands of noise (or single frequency components) which are measured separately are to be combined the resulting noise level in dB can be calculated from the dB values of the separate noise bands as follows:

1. Calculate the difference (in dB) between the two bands $L_2 - L_1$.
2. From the chart given below a dB-value, ΔL, to be added to the highest of the two band levels is found (see example below).
3. The result, $L_R = L_2 + \Delta L$, is the required resultant level in dB, and can be treated as a single value by further addition.

Example:

Noise levels of the two bands:

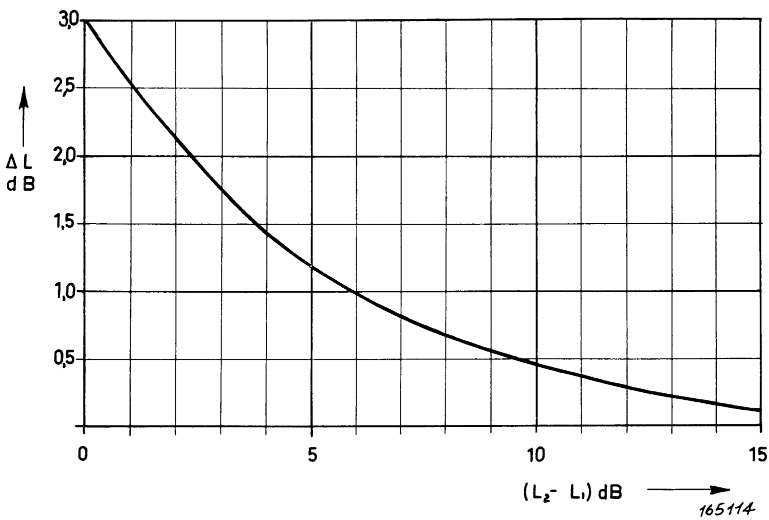
85 dB re. 2×10^{-4} μbar (L_2) 82 dB re. 2×10^{-4} μbar (L_1)

$L_2 - L_1 = 85 - 82 = 3$ dB.

From the chart is found: $\Delta L = 1.7$ dB.

The resulting level is thus 86.7 dB re. 2×10^{-4} μbar.

Decibel Addition Chart



b) *Subtraction.*
This case is important when signals are measured in the presence of background noise, and the signal to noise ratio is smaller than some 20 dB. For greater signal/noise-ratios the effect of the background noise upon the measurement can in most cases be neglected, see also chart below.

The procedure to be applied when the effect of the background noise is to be taken into account is as follows:

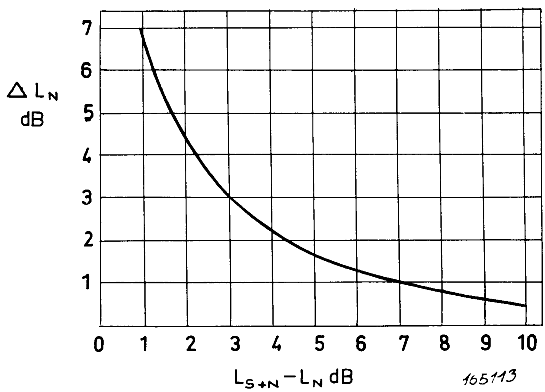
1. The signal + background noise, L_{S+N}, is first measured (normal measurement), whereafter the distinct signal source is shut off and the background noise, L_N, measured alone. Both measurements are to be made in dB and the difference, $L_{S+N} - L_N$, calculated.
2. The dB-value, ΔL_N, to be subtracted from the L_{S+N}-value is found from the chart below.
3. The result, $L_{S+N} - \Delta L_N$ is the correct level of the signal being measured.

Decibel Subtraction Chart

Example:

L_{S+N}	= 60 dB
L_N	= 53 dB
$L_{S+N} - L_N$	= 7 dB
ΔL_N	= 1 dB
$L_{S+N} - \Delta L_N$	= 59 dB

The resulting level is thus 59 dB re. 2×10^{-4} μbar.



Octave Conversion

When dealing with acoustics, an octave is an expression of a relative measure of frequency, i.e. one octave above or below a certain frequency f_o means $2 \times f_o$ or $\frac{1}{2} \times f_o$ respectively.
Mathematically it is expressed by:

$$\frac{f}{f_o} = 2^n$$

where n may be positive, negative, a fraction or a number of octaves and f_o the frequency to which the frequency f is referred.

By taking the logarithm on both sides of the equation above, it is derived:

$$\log_{10} \frac{f}{f_o} = n \times 0.3010$$

from which f or n for a given n or f respectively can be calculated.
In Fig. 2 will be found a graph where n, positive and negative, is plotted versus relative frequency $\frac{f}{f_o}$.

Example:

$+\frac{3}{6}$ octave $= +\,0.5$ octave

reads $\frac{f}{f_o} = 1.41$

$\div\frac{1}{6}$ octave $= -\,0.17$ octave

reads $\frac{f}{f_o} = 0.89$

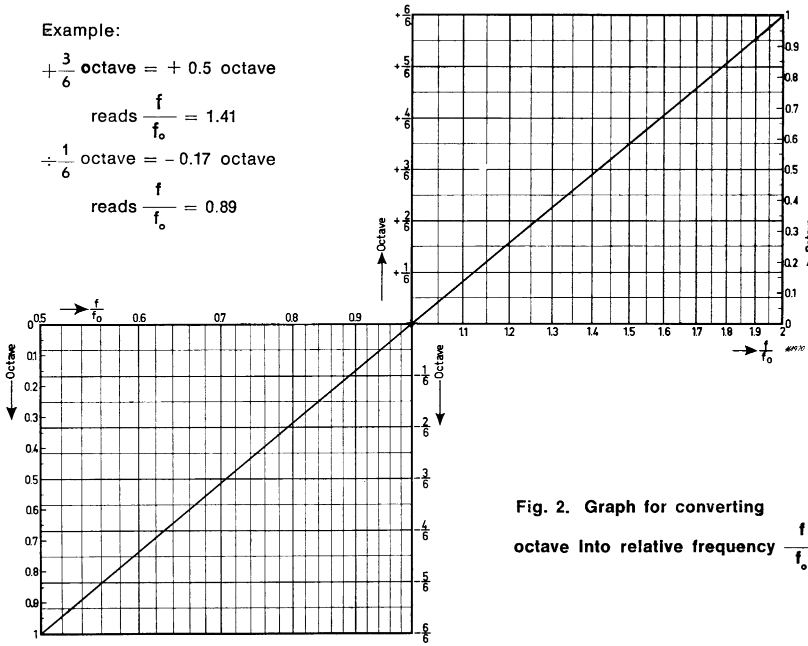


Fig. 2. Graph for converting octave into relative frequency $\frac{f}{f_o}$

Effective Noise Bandwidth

An ideal filter is defined as a filter with zero attenuation within the pass-band and infinite attenuation elsewhere. The effective noise bandwidth of a practical filter is defined as the bandwidth of an ideal filter which has uniform transmission in its pass-band equal to the maximum transmission of the practical filter and transmits the same power of white noise, see also Fig. 3.

In mathematical form:

$$\Delta f = \frac{1}{G_{max}} \int_{o}^{\infty} G(f)df$$

where:

Δf = effective noise bandwidth.

G(f) = power gain of the filter as a function of frequency.

G_{max} = maximum value of G(f).

f = frequency.

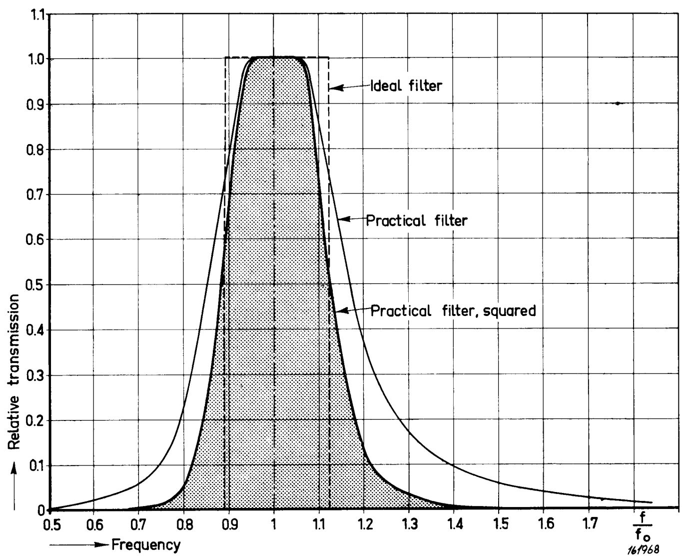


Fig. 3. Characteristics of an ideal and practical filter. Note both co-ordinates are linear.

Power Spectrum Density

The power spectrum density of a complex signal is the average power per cycle bandwidth. If the power spectrum density is constant in a small frequency interval, Δf, and the total power in this interval is w Δf then the power spectrum density within Δf is:

$$w(f) = \frac{W\Delta f}{\Delta f}$$

The use of the expression w(f) means that even if w(f) is constant within the small frequency interval Δf it will, in general, change if the center frequency of Δf changes over a larger frequency range.

Averaging Accuracy of Rectified Noise

When a band of random noise, Δf, is rectified and averaged over a certain period of time, T, the relative uncertainty (standard deviation) of the measurement is:

$$\varepsilon = \frac{C_o}{\sqrt{\Delta f \times T}}$$

where:

Δf = Effective noise bandwidth

T = "Ideal" averaging time $\left(\frac{1}{T}\int_0^T g^2(t)dt\right)$

c_o = Constant, discussed below.

When the measured quantity has the dimension of power, e.g. power spectral density, then $c_o = 1$. If the quantity measured has a linear dimension, such as for instance the RMS or average absolute value of a noise signal then c_o should be taken equal to 1/2.

Some Characteristic Properties of Gaussian Random Noise

Most noise signals occuring in daily life are of a more or less random nature. Such signals can only be adequately described by means of statistical methods in the form of statistical distributions and moments of the distributions. A very important statistical distribution is the so-called Gaussian (or normal) distribution, because it is so often found

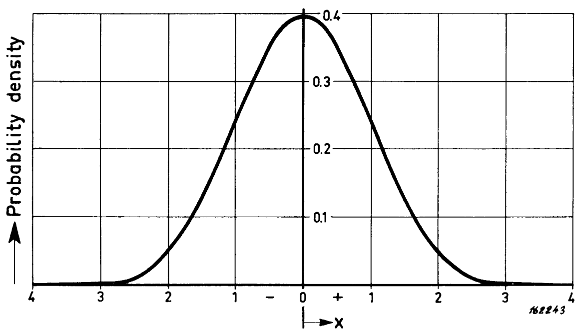


Fig. 4.

that the instantaneous values of the noise in question follow very closely, this distribution law. The shape of the Gaussian probability density curve is given mathematically by the formula:

$$p(x) = \frac{1}{\sigma\sqrt{2\pi}} \times e^{-\frac{1}{2}\left(\frac{x}{\sigma}\right)^2}$$

Here x is the instantaneous value of the noise signal and, when the process is ergodic, σ is the RMS value of the noise. The actual curve is shown in Fig. 4. A number of specific properties of Gaussian random noise are known and some of the most important ones are given in the following:

1. The ratio between the RMS value and the average absolute value is

$$\frac{\text{RMS}}{|\text{average}|} = \sqrt{\frac{\pi}{2}} = 1.25 \qquad \text{(Approximately 2 dB)}$$

2. The expected number of zero-crossings with positive slope in an ideal band of noise ranging from f_1 to f_2 is:

$$N_o = \sqrt{\frac{f_2^3 - f_1^3}{3\,(f_2 - f_1)}}$$

(This may be regarded as an expected average frequency).

3. The expected number of maxima in the same noise band as considered under 2. is:

$$N_{max} = \sqrt{\frac{3}{5}\,\frac{(f_2^5 - f_1^5)}{(f_2^3 - f_1^3)}}$$

4. When the noise band is very narrow, i.e. $f_2 - f_1$ is small $N_{max} \sim N_o \sim f_2 \sim f_1$ and the signal appears as an irregularly modulated sinewave, see Fig. 5. Also the probability density of the signal peaks then follows a relatively simple mathematical law, the so-called Rayleigh distribution, Fig. 6.

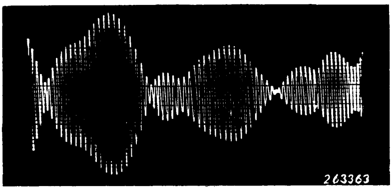


Fig. 5.

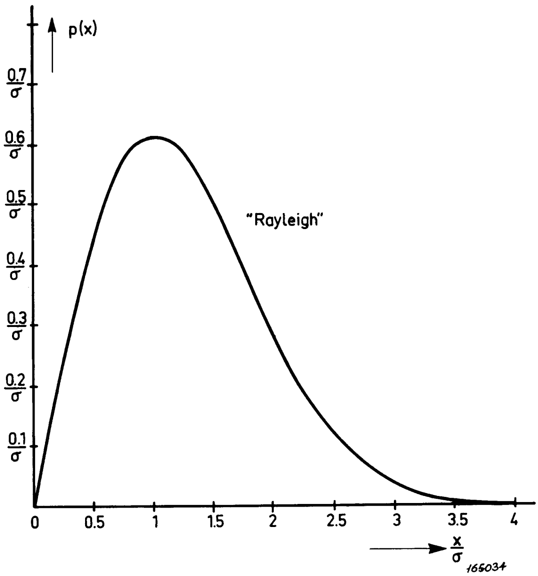


Fig. 6.

Internationally Preferred Numbers

40-series	20-series	10-series	5-series	Exact Value	Mantissa
1	**1**	**1**	**1**	10000	**000**
1.06				10593	**025**
1.12	**1.12**			11220	**050**
1.18				11885	**075**
1.25	**1.25**	**1.25**		12589	**100**
1.32				13335	**125**
1.4	**1.4**			14125	**150**
1.5				14962	**175**
1.6	**1.6**	**1.6**	**1.6**	15849	**200**
1.7				16788	**225**
1.8	**1.8**			17783	**250**
1.9				18836	**275**
2	**2**	**2**		19953	**300**
2.12				21135	**325**
2.24	**2.24**			22387	**350**
2.36				23714	**375**
2.5	**2.5**	**2.5**	**2.5**	25119	**400**
2.65				26607	425
2.8	**2.8**			28184	**450**
3				29854	**475**
3.15	**3.15**	**3.15**		31623	**500**
3.35				33497	**525**
3.55	**3.55**			35481	**550**
3.75				37584	**575**
4	**4**	**4**	**4**	39811	**600**
4.25				42170	**625**
4.5	**4.5**			44668	**650**
4.75				47315	**675**
5	**5**	**5**		50119	**700**
5.3				53088	**725**
5.6	**5.6**			56234	**750**
6				59566	**775**
6.3	**6.3**	**6.3**	**6.3**	63096	**800**
6.7				66834	**825**
7.1	**7.1**			70795	**850**
7.5				74989	**875**
8	**8**	**8**		79433	**900**
8.5				84140	**925**
9	**9**			89125	**950**
9.5				94406	**975**

Decibel and Ration Conversions

The following table has been preparred in order to facilitate the conversion from *dB* to *sound pressure ratios* and vice versa. However, with a slight modification it may also be used for dB to sound intensity (power) conversion and vice versa.

dB	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0	1.000	1.012	1.023	1.035	1.047	1.059	1.072	1.084	1.096	1.109
1	1.122	1.135	1.148	1.161	1.175	1.189	1.202	1.216	1.230	1.245
2	1.259	1.274	1.288	1.303	1.318	1.334	1.349	1.365	1.380	1.396
3	1.413	1.429	1.445	1.462	1.479	1.496	1.514	1.531	1.549	1.567
4	1.585	1.603	1.622	1.641	1.660	1.679	1.698	1.718	1.738	1.758
5	1.778	1.799	1.820	1.841	1.862	1.884	1.905	1.928	1.950	1.972
6	1.995	2.018	2.042	2.065	2.089	2.113	2.138	2.163	2.188	2.213
7	2.239	2.265	2.291	2.317	2.344	2.371	2.399	2.427	2.455	2.483
8	2.512	2.541	2.570	2.600	2.630	2.661	2.692	2.723	2.754	2.786
9	2.818	2.851	2.884	2.917	2.951	2.985	3.020	3.055	3.090	3.126
10	3.162	3.199	3.236	3.273	3.311	3.350	3.388	3.428	3.467	3.508
1	3.548	3.589	3.631	3.673	3.715	3.758	3.802	3.846	3.890	3.936
12	3.981	4.027	4.074	4.121	4.169	4.217	4.266	4.315	4.365	4.416
13	4.467	4.519	4.571	4.624	4.677	4.732	4.786	4.842	4.898	4.955
14	5.012	5.070	5.129	5.188	5.248	5.309	5.370	5.433	5.495	5.559
15	5.623	5.689	5.754	5.821	5.888	5.957	6.026	6.095	6.166	6.237
16	6.310	6.383	6.457	6.531	6.607	6.683	6.761	6.839	6.918	6.998
17	7.079	7.161	7.244	7.328	7.413	7.499	7.586	7.674	7.762	7.852
18	7.943	8.035	8.128	8.222	8.318	8.414	8.511	8.610	8.710	8.810
19	8.913	9.016	9.120	9.226	9.333	9.441	9.550	9.661	9.772	9.886

As 0 dB corresponds to a sound *pressure* ratio of 1 and 20 dB to a sound *pressure* ratio of 10 practically all ratio to dB conversions (and vice versa) are possible by means of the table.

Sound Pressure Calculations:

1) *dB-to-ratio conversion:*
   Subtract a whole number of n $\times$ 20 from the dB value to be converted which gives a positive remainder between 0 and 20. Look up the ratio in the table corresponding to the remainder. The value sought is then $10^n \times$ value from the table.

   Numerical Example:
   If the sound pressure level is 74 dB re. 0.0002 μbar what is then the actual sound pressure (in μbar)?

   Answer: 74 dB = (3 $\times$ 20 + 14) dB.
   14 dB corresponds to a pressure ratio of 5.012 (according to table).

   Thus when $20 \log \frac{p}{p_o} = 74$ dB, then:

   $\mathbf{p} = 10^3 \times 5.012\ p_o = 10^3 \times 5.012 \times 0.0002 \approx \mathbf{1}$ **μbar.**

2) *Ratio-to-dB conversion:*
   Divide the pressure ratio to be converted by 10^n so that a number, A, is obtained which lies between 1 and 10 (i.e. ratio = A $\times$ 10^n).

Look up the number in the table which is as close to A as possible. Add the dB-value (from the table) corresponding to this number to n $\times$ 20. The result is the desired sound *pressure* level in dB.

Numerical Example:
If the sound pressure is found to be 3.56 μbar what is then the sound pressure level in dB re. 0.0002 μbar?

Answer: $\frac{}{} = \frac{3.56}{0.0002} = 17800 = 1.78 \times 10^4$

From the table it is found that a pressure ratio of 1.78 corresponds to approximately 5 dB, thus:
Sound Pressure Level = 5 + 4 $\times$ 20 = **85 dB re. 0.0002 μbar.**

Sound Intensity (Power) Calculations.

1) *dB-to-ratio conversion:*
Multiply the dB-value to be converted by 2 and proceed as under "Sound Pressure Calculations" above.
Note: The reference level is in this case normally (10^{-16} W/m^2) which corresponds to the intensity of a free progressive sound wave in atmospheric air with a sound pressure of 0.0002 μbar (2×10^{-5} N/m^2).

Numerical Example:
If the sound intensity level is 83 dB re. 10^{-16} W/cm^2 what is then the actual sound intensity level in W/cm^2?
Answer: 83 dB $\times$ 2 = 166 = (8 $\times$ 20 + 6).
From the table it is found that 6 dB corresponds to a ratio of 1.955. Thus, the sound intensity level is:
P = $2 \times 10^8 \times 10^{-16}$ = **2×10^{-8} W/cm^2.**

2) *Ratio-to-dB Conversion:*
Proceed as under "Sound Pressure Calculations" above and divide the result by 2.

Numerical Example:
If the sound intensity is found to be 5×10^{-7} W/cm^2 what is then the sound intensity level in dB re. 10^{-16} W/cm^2?

Answer: $\frac{p}{p_o} = \frac{5 \times 10^{-7}}{10^{16-}} = 5 \times 10^9$

From the table it is found that a ratio of 5 corresponds to approximately 14 dB, thus:

Sound Intensity Level $= \frac{14 + 9 \times 20}{2} =$ **97 dB re. 10^{-16} W/cm^2.**

Conversion Wavelength – Frequency

The transformation scale is given by the speed of sound in the medium in question, and one *wavelength,* λ, which corresponds to one period of vibration, T, i.e. $\lambda = cT$, where c is the speed of sound. More often this relationship is given in the form of an equation connecting the wavelength to the vibration frequency:

$$\lambda = \frac{c}{f}$$

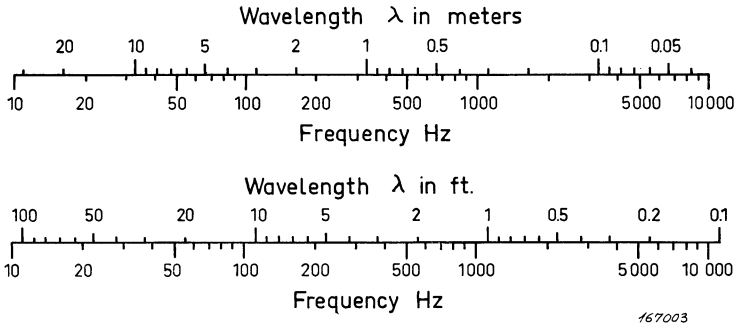


Fig. 7. Wavelength in air versus frequency under normal conditions. Speed of sound c = 343 m/sec.

Systems of Units

Unfortunately for the practicing engineer a variety of measuring systems have been developed in the course of time. Each of these systems have their advantages and disadvantages. However, it has been generally recognized in the later years that the MKS (or Giorgi) system seems to be the most practical one to use for engineers as well as for scientists, and most modern textbooks refer to this system.

Another system which has very wide recognition in the scientific world is the basic c.g.s. (centimetre, gram, second) system.

Finally a system, which was mainly developed for the convenience of the practicing engineer, the so-called technical system of units has been widely used in many countries.

To allow a conversion of units from one system to the other the tables given below have been prepared.

Units of Force

MKS-system		C.G.S.-system		Techn.-system
1 Newton	=	10^5 dyn	=	0.102 kp*)
10^{-5} Newton	=	1 dyn	=	1.02×10^{-6} kp*)
9.81 Newton	=	9.81×10^5 dyn	=	1 kp*)

*) kp = kilopond (kg-force)

In some countries the weight is commonly measured in lb and the force in lbf. (pound-force).

The connection between lbf. and kp is: 1 lbf. = 0.4536 kp.

Units of Pressure

MKS-system	C.G.S.-system	Techn.-system
1 Newton/m^2	= 10 dyn/cm^2	= 0.102 kp/m^2
0.1 Newton/m^2	= 1 dyn/cm^2 = 1 μbar	= 1.02 $\times$ 10^{-2} kp-m^2
9.81 Newton/m^2	= 98.1 dyn/cm^2	1 kp/m^2

In some countries pressure is also measured in lb/sq.in. The relation between lb/sq.in and kp/m^2 is: 1 lb/sq.in = 703.06 kp/m^2.

Units of Power

MKS-system	C.G.S.-system	Techn.-system
1 Watt	= 10^7 erg/sec	= 0.102 kpm/sec.
10^7 Watt	= 1 erg/sec.	= 1.02 $\times$ 10^{-6} kpm/sec.
9.81 Watt	= 9.81 $\times$ 10^7 erg/sec.	= 1 kpm/sec.

The power capacity of a system is sometimes given in HP (Horse Power). The relation between metric HP and Watts is

1 HP (metric) = 735 Watts.

Standard Reference Levels

1 Atmosphere = 1.013 bar = 1.033 Kp/cm^2 = 14.70 lbs./sq.inch = 760 mm Hg = 29.92 inches Hg.

Acceleration of Gravity:

g = 980.665 cm/sec^2 = 32.174 ft/sec^2 (standard or accepted value).

Sound Level:

The common reference level is the audibility threshold at 1,000 Hz i.e. 0.0002 dyne/cm^2, 2 $\times$ 10^{-4} μbar, 2 $\times$ 10^{-5} N/m^2, 10^{-16} watt/cm^2.

Basic Characteristics of a Periodic AC-Signal

The following mathematical definitions all refer to an electrical signal e(t), of fundamental frequency $f = \frac{1}{T}$.

Peak Value:

$e_{peak} = e_{max}$ (t) is the maximum value of e(t) within the time interval T.

Average Value:

$$e_{average} = \frac{1}{T}\int_0^T |\,e(t)\,|\,dt$$

RMS Value:

$$e_{RMS} = \sqrt{\frac{1}{T}\int_0^T [e(t)]^2\,dt}$$

From these basic definitions are derived:
The crest factor:

$$F_c = \frac{e_{peak}}{e_{RMS}}$$

and the form factor:

$$F_f = \frac{e_{RMS}}{e_{average}}$$

For a sinusoidal function $e(t) = E \sin \omega t$, the different values will be:

$$e_{peak} = E$$

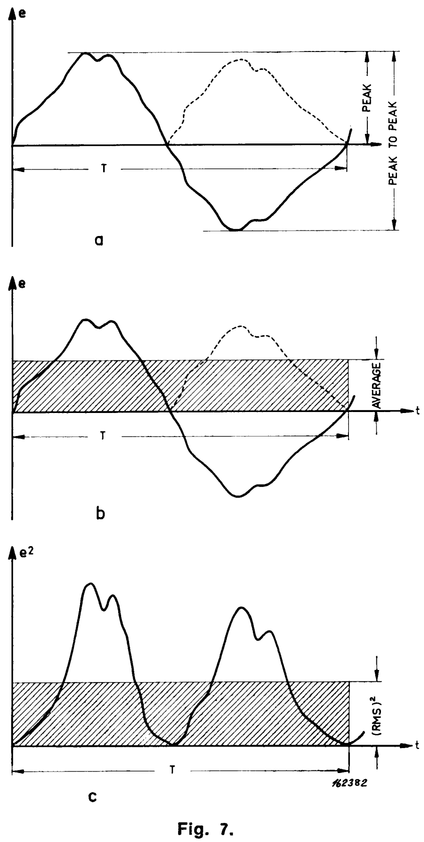


Fig. 7.
Fig. 7a. Peak value of a periodic signal.
Fig. 7b. Average value of a periodic signal.
Fig. 7c. Squared RMS value of a periodic signal.

$$e_{average} = \frac{2E}{\pi} = 0.636\ E$$

$$e_{RMS} = \frac{E}{\sqrt{2}} = 0.707\ E$$

$$F_c = \sqrt{2} = 1.414$$

$$F_r = 1.11$$

Fig. 7a shows the peak value, and Fig. 7b the average value. The latter is determined in such a way that the hatched area equals the total area between the e(t)-curve from 0 to T and the axis of abscissae. Finally the squared RMS value as indicated in Fig. 7c is seen to be the average value of the squared signal e(t). The RMS value is naturally the square root of the one indicated on the figure.

Conversion of Acceleration

1	m/sec^2	cm/sec^2	ft/sec^2	in/sec^2
g	9.81	981	32.2	386
0.102	1	100	3.281	39.37
0.00102	0.01	1	0.0328	0.3937
0.03109	0.3048	30.48	1	12
0.00259	0.0254	2.54	0.0833	1

Single Degree of Freedom System

M = mass (kg)

K = stiffness (Newt/m)

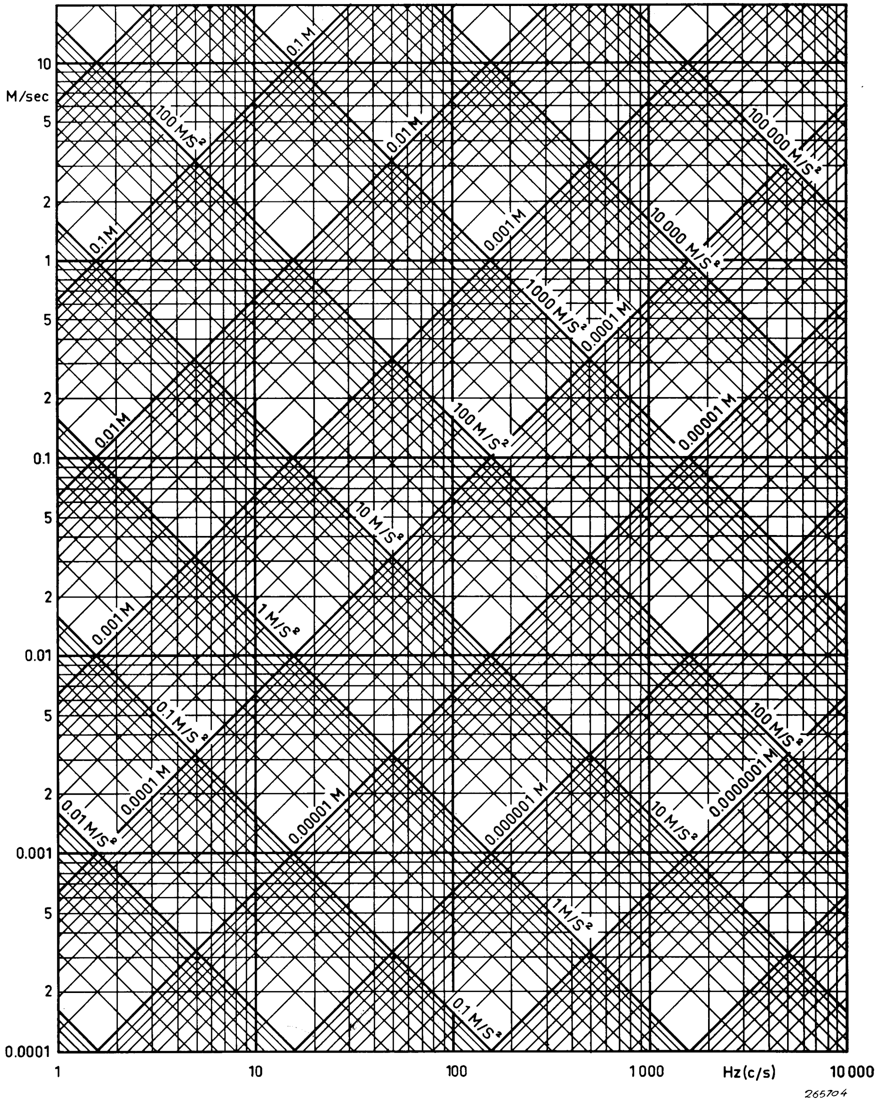
$$\omega_o = \sqrt{\frac{M}{K}} = 2\pi \times \text{resonance frequency}$$

$$\omega_o = \sqrt{\frac{g}{\Delta_{st}}}$$ where Δ_{st} = static deflection of the mass

For Single Frequency (Sinusoidal) Vibration

Acceleration	Velocity	Displacement
a cos ωt	$\frac{1}{\omega}$ a sin ωt	$-\frac{1}{\omega^2}$ a cos ωt
$-\omega$ v sin ωt	v cos ωt	$\frac{1}{\omega}$ v sin ωt
$-\omega^2$ d cos ωt	$-\omega$ d sin ωt	d cos ωt

Frequency, Acceleration, Velocity, Displacement Nomograph.
(RMS-values)



Conversion Measurements

Length:

1 inch = 1,000 mils	(") in.	= 25.40 mm
1 foot = 12 inches	(') ft.	= 30.48 cm
1 yard = 3 feet = 36 inches	yd.	= 91.44 cm
1 fathom = 6 feet	fath.	= 1.8288 m
1 rod = 5.5 yards	rod	= 5.0292 m
1 mile	mile	= 1609 m

Area:

1 circular mil (1 mil Ø)	c.m.	= 507×10^{-6} mm^2
1 square mil	sq.mil	= 6.4516×10^{-6} mm^2
1 square inch	sq.in.	= 6.4516 cm^2
1 square foot	sq.ft.	= 0.09290 m^2
1 square yard	sq.yd.	= 0.8361 m^2

Volume:

1 cubic inch	cu.in.	= 16.387 cm^3
1 cubic foot	cu.ft.	= 0.02832 m^3
1 cubic yard	cu.yd.	= 0.7646 m^3
1 pint	pint	= 0.56825 l
1 gallon = 8 pints	Brit.gal.	= 4.546 l
1 gallon (US)	US gal.	= 3.785 l

Weight:

1 ounce	oz.	= 28.35 g
1 pound = 16 ounces	lb.	= 453.59 g
1 short ton (USA)	US.to.	= 907.185 kg
1 long ton (Engl.)	Brit.to.	= 1.016 t

Temperature:

1° Fahrenheit	F°	$= C° \times \frac{5}{6} + 32°$
1° Celsius	C°	$= \frac{5}{9} (F - 32)$

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